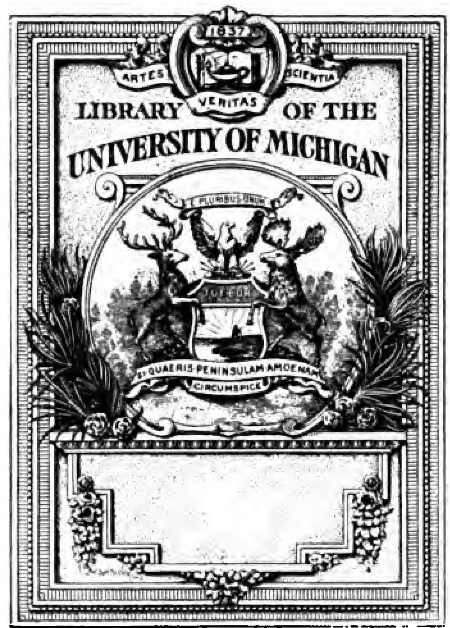

1837
ARTES
VERITAS
SCIENTIA
LIBRARY OF THE
UNIVERSITY OF MICHIGAN
E PLURIBUS UNUM
TUEBOR
SI QUAERIS PENINSULAM AMOENAM
CIRCUMSPICE

10105

JOURNAL OF GEOLOGY

THE

JOURNAL OF GEOLOGY

A Semi-Quarterly Magazine of Geology and Related Sciences

VOLUME XV

CHICAGO
The University of Chicago Press
1907

Published
February, March, May, June, August, September,
November, December, 1907

Composed and Printed By
The University of Chicago Press
Chicago, Illinois, U. S. A.

CONTENTS OF VOLUME XV

NUMBER I

NUMBER II

NUMBER III

NUMBER IV

NUMBER V

NUMBER VI

NUMBER VII

NUMBER VIII

THE

JOURNAL OF GEOLOGY

JANUARY–FEBRUARY 1907

A DRAINAGE PECULIARITY OF THE SANTA CLARA VALLEY AFFECTING FRESH-WATER FAUNAS

J. C. BRANNER

In 1890 Professor Joseph Le Conte read before the Geological Society of America an article on Tertiary and post-Tertiary changes of the Atlantic and Pacific coasts, in which he expressed the opinion that the drainage of the great valley of California formerly flowed into the Pacific Ocean, not through the Golden Gate as it does now, but by way of the Santa Clara Valley and the Bay of Monterey.[1] His reasons for this theory are: (1) that there is no submerged channel off the Golden Gate; (2) that there is a submerged valley off the Bay of Monterey, while (3) the watershed between the north end of the Santa Clara Valley and that now flowing into Monterey Bay by way of the Pajaro River is less than a hundred feet high at its lowest point. A few years later Dr. C. H. Gilbert, professor of zoölogy at Stanford University, in studying the fishes of California, observed a remarkable resemblance between certain fishes found in the Sacramento drainage and in the streams flowing into the Bay of San Francisco, and those found in the Pajaro, Salinas, San Lorenzo, and other streams flowing into the Bay of Monterey. The fishes here referred to are not of kinds that descend into salt water; their present distribution therefore cannot be explained by that kind of migration. It can only be accounted for by some ancient direct connection between the streams in question. This work has been greatly extended by

[1] *Bulletin of the Geological Society of America*, Vol. II (1891), p. 326.

Professor Snyder, of the Department of Zoölogy, Stanford University.[2]

In accounting for the distribution of these fishes, the theory of Dr. Le Conte seemed to meet the requirements of the case fairly well. To understand the principal peculiarities of this fauna, it was only necessary to imagine the Golden Gate closed and the Sacramento Valley drainage flowing down the Santa Clara Valley and emptying into the Bay of Monterey. The Bay of San Francisco would thus be a body of fresh water, and the fishes of the upper Sacramento could ascend streams flowing into the fresh-water bay and into the Santa Clara Valley. There is some difficulty in comprehending how the fishes from the Pajaro, through which the waters are supposed to have entered the Bay of Monterey, could get into the Salinas a few miles to the south, and into the San Lorenzo which enters the bay twelve miles or more northwest of the mouth of the Pajaro; but no stress need be laid just now on the relation of the Pajaro to other streams flowing into the Bay of Monterey. Recent study of the geology southwest of San José has raised serious doubt regarding Dr. Le Conte's conclusions and necessitated a closer scrutiny of the facts offered in their support.

The first two reasons brought forward by him—namely, (1) that there is no submerged channel in front of the Golden Gate, and (2) that there is such a channel in the Bay of Monterey—are sufficiently warranted by the hydrographic charts. The Monterey channel is clearly exhibited in one of the charts accompanying Professor George Davidson's "Submerged Valleys of the Coast of California," published in the *Proceedings of the California Academy of Sciences*, Third Series, Vol. I, pp. 73–101, S. F. 1897. The question is here raised, however, regarding the assumed height of the watershed in the Santa Clara Valley between the drainage into the Bay of San Francisco and the drainage into the Bay of Monterey. Dr. Le Conte says it is less than a hundred feet above sea-level, and it is apparently assumed that with the Golden Gate closed the drainage of the great valley would rise and flow over this notch and pass down the Pajaro River to the Bay of Monterey.

[2] J. O. Snyder, "Notes on the Fishes of the Streams Flowing into San Francisco Bay, Cal.," *Report of the U. S. Fish Commission*, 1904.

The line of the Southern Pacific Railway passes over the watershed referred to at Madrone station, and the elevation at that place, as officially published, is 345 feet.[1] This elevation, though much greater than was supposed, would not alone, however, seriously interfere with Dr. Le Conte's theory. But if we imagine the Golden Gate closed, it is necessary, in order to test the validity of the hypothesis, to know where the lowest gaps are through which the water could escape to the sea. If the Madrone saddle, even with an elevation of 345, is the lowest pass to the ocean, then of course the water would flow out that way. But the Coast Survey's topographic map of San Francisco shows that, if the present Golden Gate were closed and the water compelled to find a new outlet, it would first flow over the divide at Colma seven miles south of the City Hall of San Francisco; this gap has an elevation of only 190 feet above tide. North of San Francisco it would also flow into the sea from Richardson Bay near Sausalito by way of Elk Valley, which has a watershed only 190 feet above tide-level.

Without further inquiry into the existence of other low divides between the bay and the ocean, it is evident that, even if it were admitted that the Golden Gate be a late topographic development, the Sacramento drainage did not lately flow into the Bay of Monterey by way of the Santa Clara Valley. It is evident also that the resemblance between the fish faunas of the Sacramento drainage and the streams flowing into Monterey Bay must be sought elsewhere.

The accompanying map shows in a general way the present drainage of the Santa Clara Valley in the vicinity of Madrone. Attention is directed to Coyote Creek, which emerges from the Mount Hamilton range opposite Madrone station and flows northwestward into the Bay of San Francisco. This stream, above where it emerges from the hills on to the plains, drains an area of 214 square miles, much more than any other one stream that enters the Santa Clara Valley. From the mouth of the gorge where this creek debouches on the plain a great alluvial fan spreads out toward the south and west across the entire width of the Santa Clara Valley, at this place a distance of two and a half miles. This fan forms the watershed in the valley trough between the Bay of San Francisco and the Pajaro River or

[1] Gannett's *Dictionary of Elevation*, p. 220.

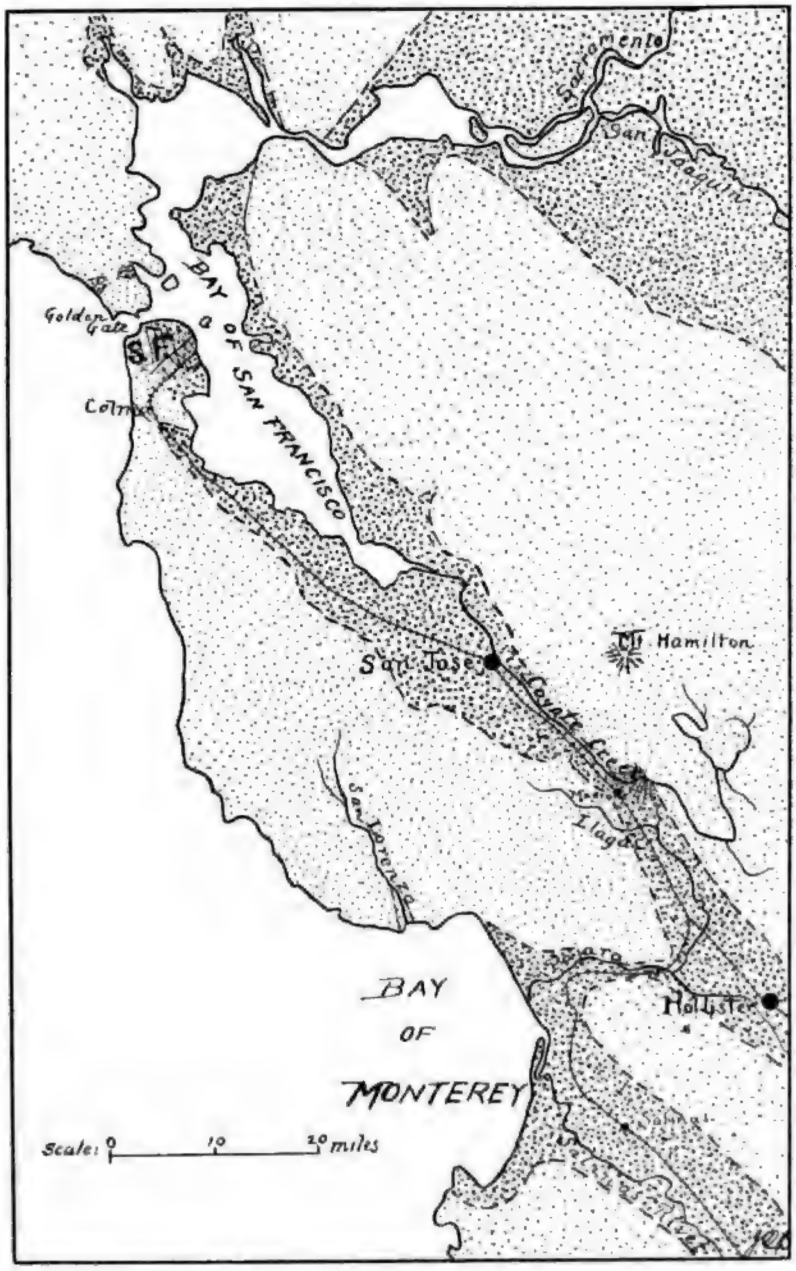


FIG. 1.—Map showing the relations of the drainage about the Bay of San Francisco and the Bay of Monterey. The more heavily shaded areas represent the flat valley lands.

the Bay of Monterey. Madrone station on the Southern Pacific Railway is at the southwestern edge of this alluvial fan, and is on the watershed at its lowest point. It will be seen from the map that upon emerging from the hills Coyote Creek bends sharply to the right and flows close to Las Animas Hills for several miles. The configuration of the materials of the alluvial fan at the mouth of the gorge shows that the Coyote has been shifting its channel of late. A terrace south of the stream, and approximately parallel with it, shows that it formerly flowed toward the west, while another and still higher terrace farther south shows that at an earlier date it flowed toward the southwest; and the general form of the alluvial fan shows that the whole fan was built by the Coyote. It is a characteristic feature of streams, in the building-up of such deposits, that they swing from side to side, flowing down over their own deposits in every direction, and shifting their channels as they become choked up by the deposit of their excess of load. The depth and position of the channel through which the Coyote now flows after emerging from the hills show that there has been no recent discharge of its waters toward the Pajaro. The general topography of the region about the mouth of the gorge suggests that the alluvial fan was built up a long while ago, and at a period when the stream was much more active than it now is—possibly during or toward the close of the glacial epoch. During the glacial epoch the streams of the region were much more vigorous than they have been since, for the coast stood at an elevation of two thousand feet or more higher than it does at present. There was therefore a greater precipitation, and during the winter months the Mount Hamilton Range must have been covered with snow which accumulated more than it does now and went off rather suddenly with the warm rains of early spring, producing much greater floods than we now have.

It follows from the form of this alluvial fan on the plain where the stream emerges from the mountains that the Coyote must have shifted from side to side in the usual fashion, especially in the early history of the alluvial cone and during the constructive period. It flowed sometimes toward the northwest, draining into the Bay of San Francisco, and at other times toward the southeast, draining through the Pajaro into the Bay of Monterey. Such a shifting of

the Coyote at the summit of the watershed would, in this fashion, afford an opportunity for the mingling of the fauna of the Pajaro and its tributaries with that of Coyote Creek and its tributaries. Fishes from the Pajaro could ascend the stream into the mountains while the water flowed toward the Pajaro, and when the stream shifted, or its waters divided, these fish could descend the Coyote.[1]

But the problem of the mingling of the fish faunas is not confined to the Pajaro and Coyote alone; it extends to the Sacramento and other streams flowing into the Bay of San Francisco and to other streams flowing into the Bay of Monterey. So long as the Bay of San Francisco is filled with salt or brackish water it is an effective barrier against the passage of these fishes.

The additional requirements of the case seem to be met by the theory of a former elevation of the coast. Indeed, not only does such a theory afford a satisfactory explanation of the mingling of the fish faunas of the streams under consideration, but it is necessary for the explanation of other phenomena more or less directly connected with this subject. That there was such an elevation is shown not only by (1) the mingling of the fish faunas of the streams referred to, and which I am unable to account for in any other way; but also by (2) the greater activity of the streams of the coast at a period not far removed geologically; by (3) the submerged valleys along the coast; and by (4) the islands off the California coast.

It is not proposed to discuss these evidences at length, but a few words may be said of the importance of each one. The evidence of greater activity of the streams is not confined to the Coyote or to the streams of any particular district, but it is common to the streams of the Coast Range and of the Sierra Nevada. The great alluvial cones of the glacial epoch are far beyond the reach of the modern

[1] The topographic peculiarity here cited is not unique. In 1892 Dr. B. W. Everman, in connection with the work of the U. S. Fish Commission, pointed out how fish may cross over the continental divide from the Columbia River basin to the Mississippi basin by way of Two-Ocean Pass. There is a similar low alluvial fan in a meadow on the watershed between the drainage of the Paraguay and of the Amazon basin. In both of these cases the watersheds permit the mingling of the existing fauna. (The Report of the Commissioner of Fish and Fisheries respecting the Establishment of Fish Cultural Stations in the Rocky Mountain Region and Gulf States, *Miscellaneous Senate Document*, No. 65, pp. 22–26 [Washington, 1892].)

streams which are now cutting into them. In the Santa Clara Valley every considerable stream that enters it, whether from the Mount Hamilton or the Santa Cruz range, has a broad alluvial fan where it emerges on the plain. The same thing is true of the streams flowing into the San Joaquin Valley, whether from the Mount Hamilton or from the Sierra side. It may be objected that the theory of the greater activity of the streams requires a change of climate. But no change is assumed other than such as would be produced by an elevation of the region.

The submerged valleys of the coast of California figured by Professor George Davidson in his paper on this subject[1] show that the coast must have stood much higher when those valleys were cut than it does at present. The reduced charts published by Professor Davidson in his article upon the submerged valleys of the coast show the following minimum elevations required in order that these valleys should again become dry land.

Near San Diego	over 3,600 feet
Near Santa Monica	over 1,200 "
Near Point Muger	over 2,400 "
East of Anacapa Island	about 1,800 "
Santa Catalina Island	over 1,800 "
Santa Cruz Channel	over 1,800 "
King Peak submerged valley, south of Cape Mendocino	over 2,400 "
Spanish Flat Valley, south of Cape Mendocino	over 1,800 "
Punta Gorda Valley, south of Cape Mendocino	over 3,500 "
Near Cape Mendocino	over 2,400 "
Carmel Bay	over 3,000 "
Monterey Bay	over 3,600 "

The dendritic topography of these submerged valleys shown by the hydrographic charts is so characteristic of land forms produced by stream erosions that there seems no escaping the conclusion that they were formed when the region was out of water. There are not always soundings enough to show the topography very far from the shore, and in all cases we seem to have discovered only the upper ends of these submerged valleys.

At the Bay of Monterey, Carmel Bay, and near San Diego, how-

[1] *Proceedings of the California Academy of Sciences,* 3d ser., "Geology," Vol. I (1897), pp. 73–103.

ever, the submarine topography is best shown, and at these places there is suggested a former elevation of the land amounting to more than 3,000 feet. In other cases the depths of the dendritic contours are only from 1,200 to 2,000 feet, but in these instances the information regarding the former edge of the land appears to be imperfect. The absence of a submarine channel off the Golden Gate is probably due to the fact that the silts from the great valley have completely buried and obscured it.

The separation from the main land of the coast islands, Santa Catalina, Santa Rosa, etc., was produced by a recent depression that left the tops of mountains or hills in the form of islands. This is suggested by the topography of the coast islands, and is borne out by the flora and fauna[1] of those islands. The finding of the remains of the mastodon upon the island of Santa Rosa marks[2] fairly well the period of the former elevation of the coast and of land connection between the present coast and those islands—that is, the separation took place in Pleistocene times.

The peculiarity of the fish faunas of certain streams referred to lies in the fact that in several cases the faunas show that streams which are now clearly separated were formerly connected. In most cases the former connection was apparently made possible by an elevation of the coast which permitted two or three streams to enter the ocean by a single mouth. It is assumed that at such time there was a single fauna in the entire river system. The later depression has submerged the mouth of the stream, and there are now two or three or more separate streams entering the sea through as many mouths, in place of a single system entering the ocean through one mouth.

In the theoretical case suggested by the accompanying figure

[1] John Van Denburgh, "The Reptiles and Amphibians of the Islands of the Pacific Coast of North America," *Proceedings of the California Academy of Sciences*, 3d ser., "Zoölogy," Vol. IV, No. 1. The author reports four amphibians, nineteen lizards, and six snakes (twenty-nine in all) on the islands, of which fifteen live on the mainland.

[2] Joseph Le Conte, "The Flora of the Coast Islands of California, etc.," *American Geologist*, Vol. I (1888), pp. 76–81; *Proceedings of the California Academy of Sciences*, Vol. V (1873), p. 152; *American Journal of Science*, 3d ser., Vol. XXXIV (1887), pp. 457–60. L. G. Yates, *American Geologist*, January, 1890, pp. 51, 52.

it is clear that when the sea came up to the "old shore" line, fish could mingle throughout the entire drainage system represented. A depression that would place the "later shore" line as indicated would cut off the southernmost branch, but would leave the fishes free to move through the other branch of the river system. A depression bringing the water up to the "present shore" would separate the original single drainage system into five different systems, while the faunas would remain more or less the same as the one that occupied the ramifications of the streams when the drainage all entered the sea through a single mouth. It is to be expected that in time the faunas diverge, and that the longer they are separated, the greater

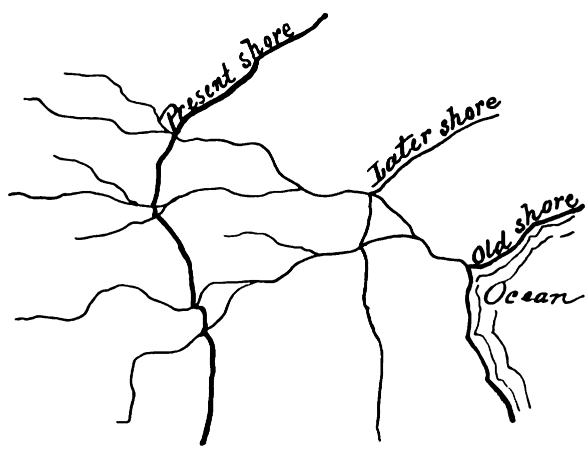


FIG. 2.—Theoretical case to illustrate the effect of coast depression on the fauna of streams that originally belonged to one system, but became separated by submergence.

the difference will be. The Coyote and Pajaro drainages have been separated since the streams ceased to be so active, and it seems quite reasonable to suppose that that period was at the close of the glacial epoch. The ichthyologists state that the fishes in the separate streams are already showing perceptible differences—differences that could only be expected after a long period of separation.

Mention should be made of the finding of marine shells in wells put down on the plain northwest of San José. In the *Tenth Annual Report* of the State Mineralogist of California for 1890, p. 610, Mr. Watt says that "marine organisms have also frequently been met

with." "Oyster shells" were obtained in a stratum of bluish sand, and a stratum of blue clay containing numerous "clam shells" is said to have been bored through about two miles north of Alviso. The finding of these marine deposits seems to show that the materials in the valley bottom are not of land origin. The deposits referred to might be either preglacial or postglacial without interfering with the theory of the elevation of the coast during the glacial epoch. In every instance, however, these marine shells have been found so near the present Bay of San Francisco that I am disposed to believe that the deposits containing them belong to the late history of the Bay and not to the more remote period.

Résumé.—The theory of the postglacial age of the Golden Gate does not appear tenable. The watershed at Madrone in the Santa Clara Valley between Coyote Creek and Pajaro River is not the lowest one between the Bay of San Francisco and the Pacific; the one at Colma is 155 feet lower, and another in Elk Valley is also 155 feet lower. The mingling of the fish faunas of streams flowing into the Bay of Monterey with those of streams entering the Bay of San Francisco is explained by the fact that Coyote Creek, descending into the Santa Clara Valley from the Mount Hamilton range at the crest of the watershed between the San Francisco Bay and the Bay of Monterey, formed an alluvial cone and swung from side to side, emptying part of the time into the Pajaro and part of the time into the Coyote. The passage of fishes between the various streams entering the Bay of San Francisco must have taken place at a time when the coast stood enough higher than it does at present to have emptied the Bay of San Francisco, and thus to have permitted fishes to descend from the Sacramento and ascend the Coyote and other streams without entering salt water. This same elevation would permit the passage of fishes between streams entering the Bay of Monterey.

It is believed that the elevation that united these streams occurred during the glacial epoch, and that it was the larger run-off of waters of that epoch that built up the alluvial cone where the Coyote debouches on the flat floor of the Santa Clara Valley.

ON THE PROBABLE GLACIAL ORIGIN OF CERTAIN FOLDED SLATES IN SOUTHERN ALASKA

ELIOT BLACKWELDER
University of Wisconsin

In the mountains east of Yakutat Bay, on the southeast coast of Alaska, a bowlder-shale terrane of unusual character has been noted by Tarr,[1] and was observed by the writer with some minuteness last summer. There is reason to believe that glaciers were instrumental in the formation of this deposit. If the supposition is correct a certain novelty attaches to the occurrence because the formation is not only old but is highly folded and slightly metamorphosed.

The rocks are well exposed in the canyons of Moser[2] and Miller Creeks and in the high bench west of them. A terrane, which is apparently the same, is that reported by Tarr from the shores of Russell Fiord.

The strata in question are several hundred feet thick and constitute a member of the Yakutat series. Typically they are conglomeratic shales, or slates, according as secondary cleavage has been developed or has not. The body of the rock is a black or dark-gray shale of relatively gritty and heterogeneous composition. In many places the matrix is definitely stratified, but elsewhere this structure is obscure or not visible.

The pebbles and bowlders in the conglomerate are the features of chief interest. Lithologically they include a large variety of rocks, some of which are known to occur not far away, while the source of others is unknown. Among them are such varieties as greenstone, gray limestone, granite, quartzite, graywacke, black slate, and flint. In size the bodies range from pebbles to bowlders of large dimensions. At least two which were more than fifty feet in length were seen imbedded in the shale, while blocks five to ten

[1] He mentions shale-conglomerate as a member of the Yakutat series. *Bulletin*, No. 284 (1906), p. 62, U. S. Geol. Surv.

[2] See map in *Bull.*, No. XXI, U. S. Fish Com.

feet in diameter are common. These pebbles and bowlders are not sorted or arranged in any way whatever. Large and small are intimately mingled and are not deposited in layers as in ordinary current-laid conglomerates. The long diameters of the bowlders are not more often parallel to the stratification than oblique to it. The shape of the pebbles and bowlders is significant, since waterworn forms were seldom observed and sharply angular bodies are even less com-

FIG. 1.—Glaciated exposure of bowlder shale in the Yakutat series. The largest bowlder is about 6 feet in diameter.

mon. The great majority of the bowlders have rounded corners and edges, but are otherwise rather irregular.

The beds of conglomerate appear to form the lower part of the Yakutat series, but the base on which they rest has not been found. Above, they seem to grade into stratified shales which are devoid of pebbles, and these in turn are followed by alternate dark shales and graywackes. The entire series has been intensely folded and broken by numerous faults. Locally, the deformation has been sufficiently

severe to distort pebbles in the conglomerate and to develop secondary cleavage in the shales. A number of the pebbles and small bowlders were dug out of the matrix, and carefully examined for surface markings, such as glacial striae, but without success. The shale usually adheres more or less closely to the pebbles imbedded in it, as if it had been actually welded to their surfaces. On this account no favorable exteriors were obtained.

The age of the formation is not yet definitely known. The Yakutat series has been assigned to the Jurassic by Ulrich,[1] on the basis of fossils found in rocks near Kodiak which are thought to be the same age; but Wright[2] is inclined to regard it as somewhat older—probably late Carboniferous.

The interpretation of the shale conglomerate is beset with some difficulties arising from insufficient data, but the facts at hand seem, nevertheless, to indicate that the deposits are of glacial origin. The lack of striations on the bowlders is believed to be largely due to subsequent deformation which has defaced or obscured the original surfaces on which such markings may have been made. The large size and the variations in both size and composition among the bowlders seem incompatible with the hypothesis that the beds have been formed entirely by aqueous currents. The subangular yet irregular shapes of the bodies are also more suggestive of glacial origin than of any other. There is one feature of the formation which is sufficient, however, to prove that even if glacial it is not an ancient deposit of till or moraine, namely, the distinct stratification. The shale matrix was evidently accumulated in quiet waters where conditions favored the settling of clays and silts in successive horizontal layers. A suggestive condition now prevails in this very region: in the broad estuary called Yakutat Bay, fine sediments are doubtless now accumulating; at the same time abundant icebergs drift out from the glaciers at the head of the bay and eventually melt before they reach the Pacific. Obviously the bowlders and finer débris enclosed in this floating ice are strewn over the bottom of the bay, and it may be supposed that the result is a stratified argillaceous

[1] E. O. Uhlrich, *Harriman Alaska Expedition* (1904), Vol. IV.

[2] C. W. Wright, in conversation with the writer at the close of the field season of 1906.

formation containing in random arrangement an abundance of bowlders and smaller fragments of rocks of various sizes, shapes, and compositions. It seems probable that the shale conglomerate of the Yakutat series had a similar origin—that it is in fact a marine shale enclosing the contributions of icebergs derived from local glaciers of late Paleozoic or early Mesozoic age.

NOTES ON GLACIATION IN THE SANGRE DE CRISTO RANGE, COLORADO[1]

C. E. SIEBENTHAL

In connection with an examination of the artesian basin of the San Luis Valley, Colorado, in 1903, several opportunities were had to make observations in the Sangre de Cristo Mountains, and various notes on the glaciation of that range are here recorded.

Attention has heretofore been called to glaciation on the eastern slope of these mountains by J. J. Stevenson,[2] who describes and figures the well-developed Grape Creek moraine, about midway of the range north and south. F. M. Endlich[3] also alludes to small indications, of glaciation, so uncertain in their character that he prefers to disregard them altogether. As a matter of fact, not only has the range suffered general glaciation, but even at present contains two living glaciers.

No pretense is made to completeness, individually or collectively, for the following notes. The observations were for the most part confined to the western side of the range. The sharp precipitous western slope merges into the great alluvial slope which skirts the western base of the range. Each stream valley which heads against the crest-line has its valley trains of glacial débris, which ordinarily reach down to and, at an elevation of about 9,000 to 9,500 feet above tide, crown the alluvial cones making up the alluvial slope.

The northernmost glaciation observed is in Black Canyon, just east of Orient Station on the Denver & Rio Grande Railway. Here are lateral moraines on each side of the creek 100–200 feet in height, and reaching nearly or quite to the lower end of the canyon.

The next canyon to the south in which morainic deposits came to the notice of the writer is Willow Creek, east of the village of Crestone.

[1] Published by permission of the Director of the United States Geological Survey.

[2] *U. S. Geographical and Geological Survey West of the 100th Meridian*, Vol. III (1875), pp. 434, 435.

[3] *U. S. Geological and Geographical Survey of the Territories, Annual Report*, 1875, p. 220.

FIG. 1.—Willow Creek Park, looking up the glaciated trough of Willow Creek.

The view looking up this creek (Fig. 1) shows Willow Creek Park in the immediate foreground. This is a natural meadow, 80 or 100 acres in extent, formed by the draining of a glacial lake. Two existing lakes are found in Willow Creek Valley above the park—one a beautiful, clear, deep pool half-way between the Park and the summit, and the other a smaller one in the cirque at the head of the creek. Polished surfaces, striae, and other evidences of glaciation are common all along the valley.

The next moraine visited was that of South Zapata Creek, the northernmost of the circle of radial streams which head in the Blanca massif. This moraine, as seen in the distance, just crowns the crest of the great alluvial fan which Zapata Creek has built. The foot of the moraine has an elevation of about 9,000 feet, and is 1,400 feet above the level of the valley at the foot of the fan in the vicinity of Zapata ranch house. There are two concentric moraines, the outer one about 50 feet the higher. The front of the outer moraine is about 350 feet in height. Both are covered with large bowlders. The inner one formerly inclosed a small lake, the outlet of which cut through the moraine where it adjoined the canyon wall on the north side and, once incised in the rock, has continued to cut back a narrow winding cleft, sometimes not more than two or three feet wide, down through which the water pours, forming the picturesque Zapata Falls. A lake also exists near the head of the creek.

Middle Creek, the next stream to the south, exhibits a similar crescentic moraine crowning the great spreading alluvial fan over which large bowlders are scattered from crest to base.

Bear Creek heads against the crest of the range just north of Blanca Peak. There is a very small lake in the cirque at the head of the creek, two or three small ponds down the creek some distance, and a fine little lake about 2,500 feet below the summit in altitude. There is little morainic material to be seen in the valley above the elevation of 10,000 feet. The valley is rounded and glaciated up the sides to the overhanging cliffs, but in places the glaciated portion is covered by "slide rock" or talus from the cliff. A light fall of snow will hang on the unglaciated slope and on the talus, but not on the cliffs, and after such snows the height to which the ice occupied the various creek valleys can be plainly seen from the center of San Luis Valley. At

10,000 feet elevation the trail up the creek crosses over the upper moraine on the south side, and the view shown (Fig. 2) is from this point. There are here inner and outer moraines, the latter 125–150 feet the higher. The inner moraine extends the farther out on the fan, differing in this respect from the Zapata moraines. The height of the moraine from its foot on the fan to the top of the outer ridge is approximately 500 feet. Landslides in the moraine show its constitution to be true glacial débris.

The various streams descending the south slope of Sierra Blanca likewise held their appropriate glaciers. The moraine in Little Bear

FIG. 2.—Moraines on north side of Bear Creek. Inner moraine forms a bench covered with a growth of pines.

Creek reaches barely to the mouth of the canyon at the apex of the fan. Blanca Creek has a pronounced moraine, extending beyond the mouth of the canyon and down the slope of the fan, the older, outer moraine reaching the farther, and the inner one being the higher. The two branches of Ute Creek both exhibit moraines and glaciated contours, and contain several lakes in their upper courses. The various streams which head in the Blanca massif number in their valleys some thirty lakelets, large and small.

The valley of the Huerfano, heading on the northeast side of Blanca Peak, is distinguished from the others by the presence of living glaciers—small, it is true, but characteristic. The valley of the Huerfano, up to the base of the steep north side of Blanca peak,

is a U-shaped valley with meadows and grassy patches, the lower slopes well rounded and glaciated. The lower limit of glaciation is beyond the region of the writer's observations.

On the north side of the valley, at the junction of the granite and the quartz conglomerate, a small valley has been cut out, and in this has formed the very pretty example of talus glacier shown (Fig. 3.). This mass of débris is about a third of a mile long and about 150

FIG. 3.—Talus glacier in small valley entering Huerfano Valley from the north, three miles north of Blanca Peak.

feet high at its lower termination. In the valley below several morainic trains may be seen emerging from beneath the talus glacier, showing that true glaciation preceded the formation of the talus glacier, which, from its bareness of vegetation and steep slopes, seems to be relatively recent in age. Streams of rocky material can be seen descending on to the débris, which has a remarkably smooth outline to have been formed through the agency of avalanches alone. Intermingled snow and ice must have played an important part in its formation.

The Blanca glaciers lie snugly under the steep north face of Blanca Peak as will be seen in Fig. 4, taken from a point about a half-mile north of McMillan's mine, which appears in the foreground. The glacier on the left, mostly covered with fresh snow, is the smaller. The surface of this glacier shows many small longitudinal gullies and another system running transversely. These seem to be largely due to

FIG. 4.—Blanca glaciers from the northeast.

original wind ripple-marks in the snow into which dust has settled, melting them deeper.

The north glacier, the one on the right, is shown in a nearer view (Fig. 5), taken from the moraine immediately below it with the camera tilted upward somewhat. Figure 6 is a view northward across the same glacier from a point near the southern one. These two views display the glacier very well. The width of the glacier is about 800 feet, and its greatest length is about 1,000 feet, although the ice probably extends a considerable distance farther beneath the terminal moraine. The glacier lies in a pocket on the mountain side, and the ice is prob-

ably quite thick. A prospecting tunnel, starting in the moraine below the edge of the visible ice, went horizontally in the clear ice

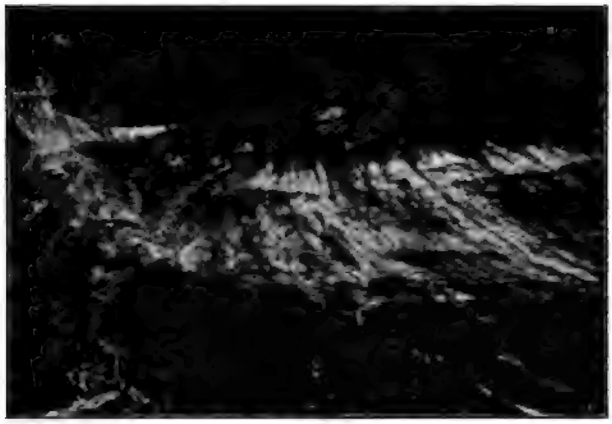


FIG. 5.—Blanca glacier, from moraine below.

FIG. 6.—Blanca glacier, looking north.

for a distance of 115 feet without reaching rock, which, taking into account the slope of the surface, demonstrates a vertical thickness of

over 80 feet. The slope of the ice surface is very steep, about 42°—quite too steep for climbing without alpinestock and ice-creepers. Two embryonic terminal morainic ridges are visible, the lower and larger one some 400 feet below the present edge of visible ice. The ice, as will be noted, shows the characteristic upturned dirt bands looped concentrically about the point of supply, and the surface of the lower half of the glacier is for the most part covered with fine black gravelly dirt, residual from the dirt bands. Many small longitudinal rivulets have cut gullies down the otherwise notably smooth surface of the ice, exposing the banded ice beneath the dirt covering. The ice itself displays characteristic *gletscherkörne* about one-tenth inch in diameter. Because of the conformation of the pocket in which the ice accumulates, the production of crevasses is impossible, with the exception of a definite *bergschrunde* which marks the line where the upper edge of the ice pulls away from the rock wall in the wasting season. The precipice above and the steep face of the glacier cause loose fragments falling upon the ice to attain great velocity in their passage across it, so that examination of the glacier is attended by considerable danger from these flying rocks.

The Blanca glaciers possess an added interest in being the southernmost existing glaciers yet reported in the Rocky Mountains, and, so far as known to the writer, the southernmost in the United States. Their latitude is 37° 35′ N., their longitude 105° 28′ W., and their elevation about 12,000 feet.

Summary.—The various stream valleys heading against the crest of the Sangre de Cristo Range held Pleistocene glaciers, the morainic remains of which fall into two systems, showing the existence of two periods of glaciation. The moraines of both systems are comparatively fresh-looking, and the outer, older ones are not noticeably more eroded than, or different topographically from, the inner, later ones. The inner moraines are sometimes lower, sometimes higher, than the outer ones, and while they usually are shorter than the older moraines, sometimes, as in Bear Creek valley, they transgress the older moraine and extend farther out upon the alluvial slope, these irregularities being due presumably to variable local conditions in Pleistocene time.

THE PLACE OF ORIGIN OF THE MOON—THE VOLCANIC PROBLEM

WILLIAM H. PICKERING

In 1879 Professor George H. Darwin propounded the view that the Moon formerly formed a part of the Earth. That it was originally much nearer to the Earth than it is at present, and is now slowly receding from us, was clearly shown by his equations. After considerable discussion, his conclusions have been accepted by the great majority of astronomers, although many of the geologists do not view them with favor. Assuming the correctness of his hypothesis, it will be of interest to determine, first, if possible, from what part of the Earth the Moon originated, and, second, to follow out our conclusions on this point and see to what results they may lead.

When the separation took place, it has been shown that the combined planet was not very much larger than is the Earth at present. It must therefore have been mostly in the solid or liquid condition. If in the latter state, it is obvious that no indication of the Moon's former place could be found at the present time. Very few astronomers or geologists today, however, believe that the Earth ever was completely liquid. It has probably always been partly solid, partly liquid, and partly gaseous. It is composed of such diverse materials, and these are exposed at different points throughout its volume to such diverse pressures, that, unless we assume it to have condensed from a highly incandescent nebula, which is unlikely, we should scarcely expect it ever to have presented a uniform liquid surface.

The surface was probably hot, but how hot we have no means of knowing. Beneath the surface, however, where radiation was impossible, much higher temperatures were found, as is still the case and in what follows we shall assume that the interior was practically liquid, or was ready to become actually so where relieved of the pressure due to the gravity of the outer layers; that is, where the centrifugal force became sufficiently high, as in the equatorial regions. Precisely how the Earth came into its present form, whether by

planetesimal condensation or otherwise, does not concern us here. We merely assume that in these early days the Earth was in much the same condition that we find it at present, except that it was hotter. We also assume that it was slowly condensing from a more bulky form, rendering fission possible.

These processes of fission and condensation we see going on all around us at the present time in the stellar universe, as indicated by the variable stars of short period and the spectroscopic binaries. It therefore requires no great stretch of the imagination to conceive that it may also have occurred on a smaller scale in the case of our Earth and Moon.

It does not follow, however, that our combined planet was ever incandescent. Indeed, this seems to be unlikely. A cold nebula which is later to condense into a sun must almost necessarily be composed largely of solid matter. The electric disturbances by which we see it, illumine only the gaseous portions, but the metallic elements must be there nevertheless, all the time unseen.

Assuming then a hot, solid, ellipsoidal Earth, with an interior more or less liquid, at least beneath the Equator, revolving on its axis once in about four or five hours, we have a picture of our as yet moonless planet as conceived by the astronomer. As it continued to cool, vast volumes of steam and other gases escaped from its interior, increasing its density and diminishing its volume.

As its volume diminished, its speed of rotation increased, until by centrifugal force, as explained by Darwin, the Moon was born. If the crust was solid, and if the Moon escaped from it, it is almost certain that a scar of some sort would have been left, and it is of interest to see if we can find it.

The specific gravity of the Earth as a whole is 5.6. That of the surface material ranges in general between 2.2 and 3.2, with an average of 2.7. The specific gravity of the Moon is 3.4. This indicates clearly that the Moon is composed of material scraped off from the outer surface of the Earth, rather than of matter obtained from a considerable depth. At the same time, the specific gravity 3.4 indicates that the layer of material removed had an appreciable thickness.

As is well known, the land and water are very irregularly dis-

tributed over the surface of our globe. If we erect a perpendicular from a point situated one thousand miles to the northeast of New Zealand and view the Earth from a distance in this direction, we shall find that very little land will be visible, while the outline of the Pacific will approach the form of a circle.

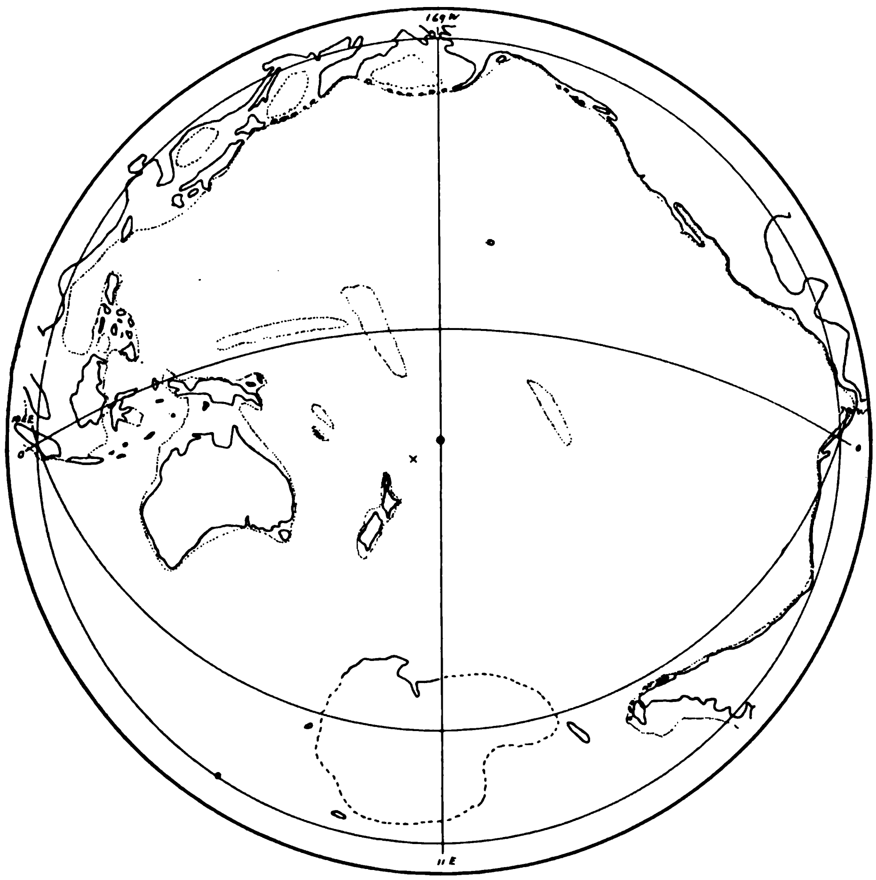


Fig. 1

Figure 1 is a map of the globe on zenithal projection, where the radii are proportional to the actual distances represented. There is no distortion, therefore, in the radial direction, and the exact shape of the Pacific with regard to a great circle is clearly shown. The inner circle represents the circumference of the globe, and is there-

fore 90° from the central point. The latitude of this point is 25° S. Away from the center the tangential distances necessarily become more and more distorted, the distortion at the circumference making them appear $\frac{\pi}{2}$, or 1.6 times too large.

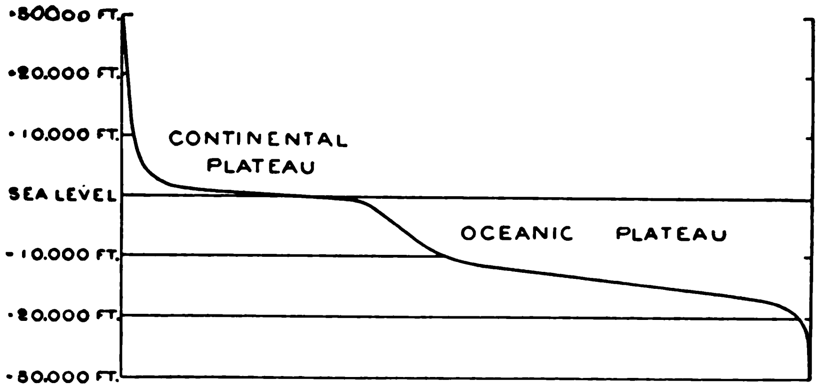


FIG. 2

Figure 2 is taken from Gilbert's *Continental Problems of Geology* (Smithsonian Report, 1892), p. 164, and is founded on the results of the Challenger Expedition as deduced by Murray. In it ordinates represent feet, and abscissas areas, the extreme abscissa representing the total area of the Earth's surface. This area is composed chiefly of two plateaus: one the continental, whose mean altitude is 1,000 feet above sea-level; the other the oceanic, whose mean altitude is $-14,000$ feet.

It will be noticed that the edge of the continental plateau is below sea-level, but not more than 1,000 feet below it. This contour may be taken, therefore, as the true boundary more properly than the water-line itself. In Fig. 1 it is indicated by a dotted line. Its position near the Antarctic continent is unknown. The location of the latter, excepting where indicated by the full line, has not been determined. The line composed of dashes therefore indicates its maximum possible area.

If we travel north 90° from the central point of Fig. 1, to the immediate vicinity of Bering Strait, and erect another perpendicular, from which we again examine the globe, we shall obtain a view resem-

bling Fig. 3. In this map, which is drawn in orthographic projection, there is no tangential distortion, and the appearance is that which the Earth would have if seen from a great distance. The vertical line is a meridian; the horizontal is a projection of the inner circle shown in Fig. 1. The continents and islands at the edges of the disk have

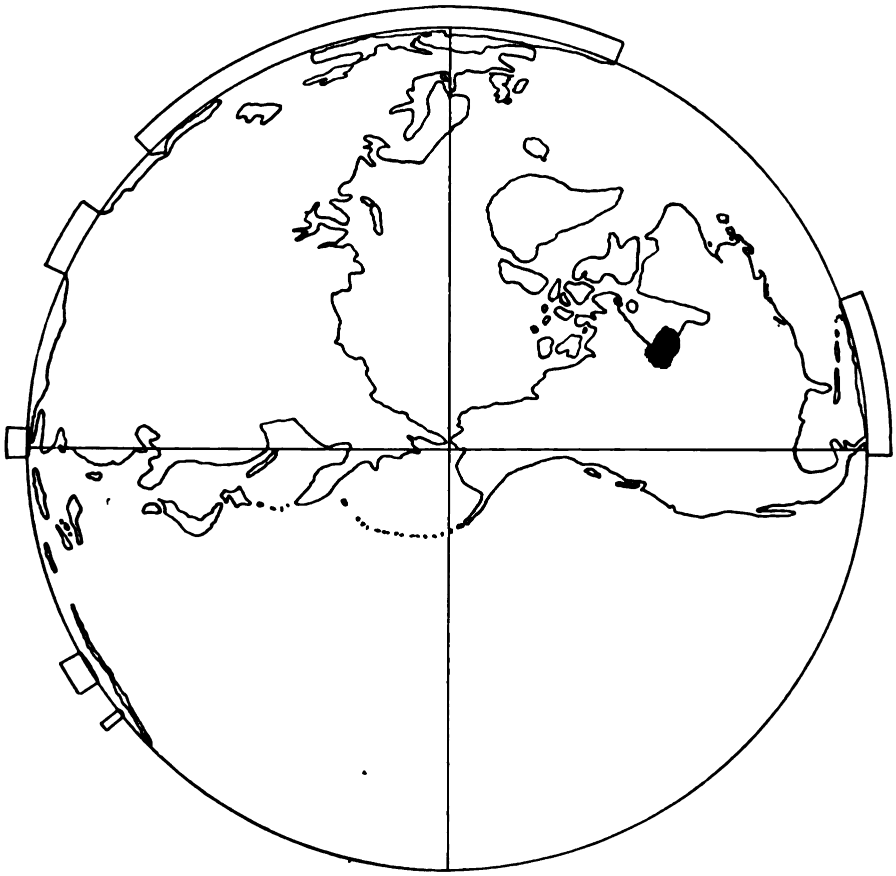


Fig. 3

been allowed to project out beyond the ocean beds in order to make more evident the systematic grouping of the continental masses on one side of the globe. With the exception of Australia, the Antarctic continent, and a small part of South America, all represented in the lower half of Fig. 1, there is no important land on the water side of the globe, not shown in Fig. 3.

An inspection of this figure shows that the Earth's center of gravity, which is the center of the circular arcs, does not coincide with its center of volume, and this deviation would be still more marked were the mobile portions of the surface—i. e., the oceans—drawn off. The center of gravity would then be slightly raised in the figure, and the center of volume still more so. The ocean side of the solid Earth has obviously a higher specific gravity than the continental side.

It is the general opinion among geologists that the continental forms have always existed—that they are indestructible. How, then, could they have originated? We know something of the permanent surface features of three bodies in the universe besides the Earth; namely, the Moon, Mars, and Mercury. None of these shows us anything resembling the irregular terrestrial distribution of the high-and low-level plains, of our continents and oceans.

If we examine more minutely the coasts of our great oceans, we shall find the Pacific bounded by a nearly continuous line of active or extinct volcanoes, and this is true whether in North or South America, Asia, the East Indies, New Zealand, or Antarctica. The only possible break is the east coast of Australia, but even here there is a line of volcanic islands, lying a short distance off the coast, stretching from New Guinea more than half-way to New Zealand. The coasts of the Pacific are generally mountainous and abrupt, and composed of curves convex toward the ocean.

The Atlantic coasts, on the other hand, are generally low, flat, and composed of curves as often concave as convex. As to volcanoes, they are few and scattering. The only conspicuous exception to the general rule is the range of the Lesser Antilles, which both in form and volcanic nature reminds us of the Pacific coast of Asia. The Indian Ocean resembles the Atlantic, except where it approaches the vicinity of the Pacific, and there the characteristic volcanoes again appear.

A curious feature of the Atlantic Ocean is that the two sides have in places a strong similarity. Figure 4 is drawn in globular projection, which is used so frequently for the hemispheres in ordinary atlases, except that in this instance the projection is carried over the Pole onto the other side. This projection gives very little distortion

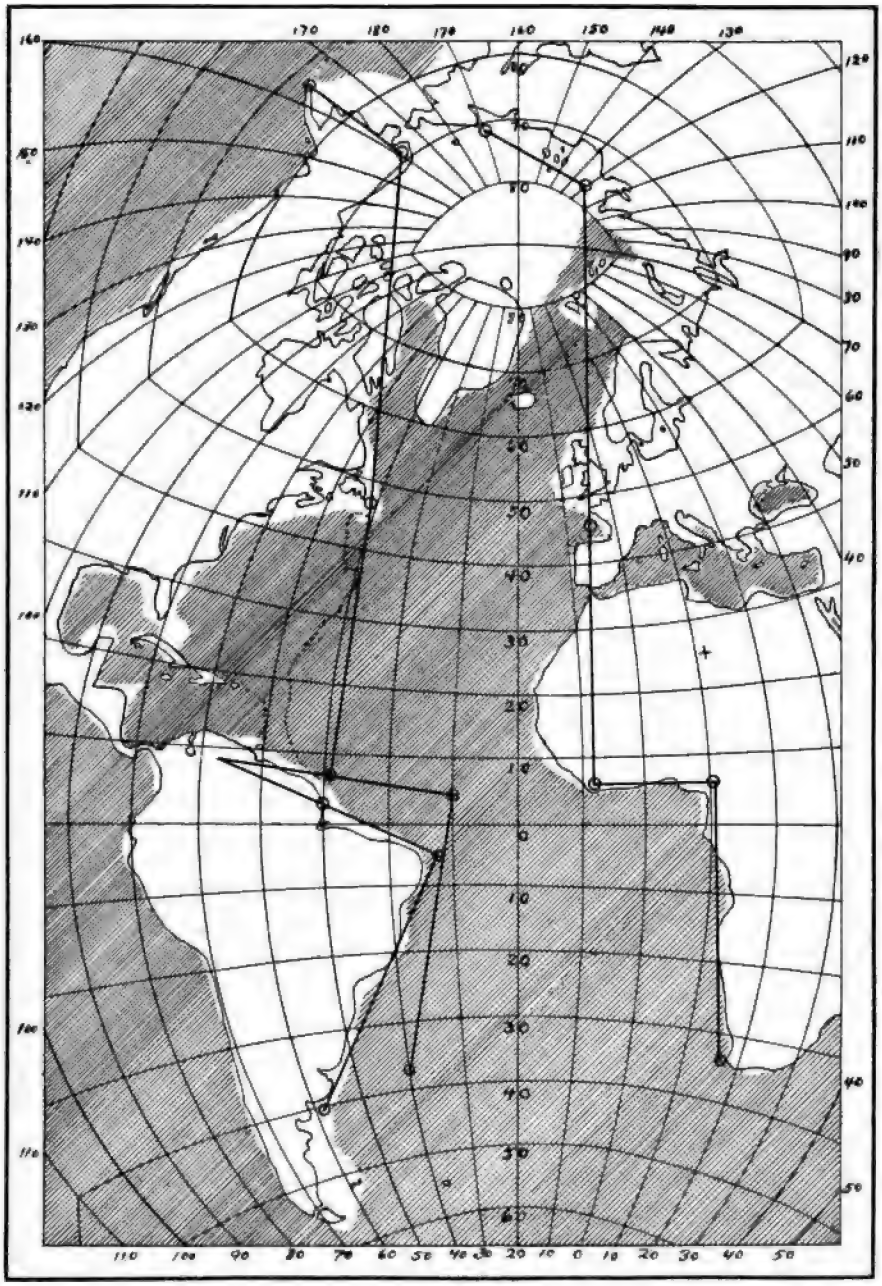


FIG. 4

in the vicinity of the central meridian, which is the portion of the map to which we shall especially refer. The shaded areas represent those parts of the ocean that are more than 1,000 feet in depth. Regarding the unshaded area between America and Asia we have no information.

When the Earth-Moon planet condensed from the original nebula, its denser materials collected at the lower levels, while the lighter ones were distributed with considerable uniformity over its surface. At the present day we find the lighter materials missing from one hemisphere. The mean surface density of the continents is about 2.7. Their mean density is certainly greater. We find a large mass of material now up in the sky, which it is generally believed by astronomers formerly formed part of our Earth, and the density of this material, after some compression by its own gravity, we find to be 3.4, or not far from that of the missing continents. From this we conclude that this mass of material formerly covered that part of the Earth where the continents are lacking, and which is now occupied by the Pacific Ocean. In fact, there is no other place from which it could have come.

Who it was that first suggested that the Moon originated in the Pacific is unknown. The idea seems to be a very old one. The object of the present paper is to find what support for this hypothesis is afforded by the results of modern science, when examined both qualitatively and quantitatively.

The volume of the Moon is equivalent to a solid whose surface is equal to that of all our terrestrial oceans, and whose depth is thirty-six miles. It seems probable, therefore, that at this time the Earth had a solid crust averaging thirty-six miles in thickness, beneath which the temperature was so high that the materials were in places liquid, and in other places only kept solid by the enormous pressure of the superincumbent material. When the Moon separated from us, three-quarters of this crust was carried away, and it is suggested that the remainder was torn in two to form the eastern and western continents. These then floated on the liquid surface like two large ice-floes.

If their specific gravity was the same as that of the Moon, 3.4, since the continental plateau averages nearly three miles higher

than the ocean bed, the specific gravity of the liquid in which they floated must have been 3.7. Later, when this liquid surface cooled, the huge depression thus formed was occupied by our present oceans.

The volcanic islands in the oceans, such as Hawaii, were obviously formed after the withdrawal of the Moon, and are analogous to the small craters scattered over the lunar *maria*. While their surface material presents no extraordinary density, the lava being full of bubbles and small cavities, interesting results have been obtained by the Coast Survey with the pendulum. Observations were made by E. D. Preston near the summit, and on the slopes of Mauna Kea, Hawaii, at altitudes of 13,060, 6,660, and 8 feet. He writes:

> It appears that the lower half of Mauna Kea is of a very much greater density than the upper. The former gives a value of 3.7 and the latter 2.1, the mean density of the whole mountain being 2.9. This is somewhat greater than that found for Haleakala [a neighboring volcano] and is notably larger than the density of the surface rocks. Indeed, this appears to be the highest value yet deduced from pendulum work.[1]

The remark of Major Dutton[2] is interesting in this connection, that a part of the bulk of these mountains is due to accumulation, and a part to uplifting. The upper half is clearly due to matter, chiefly scoria, which has been expelled from the various vents. The lower half is probably due to the slow uplifting of the former ocean bed.

It would seem as if borings carried on in this vicinity to a depth of only a few hundred feet would bring to the surface the same kind of rock material that, beneath the continents, would only be found at a depth of many miles. Presumably this material would turn out to be lava similar to that found on the surface, save that under the great pressure the innumerable little cavities, rendering the material generally so porous, would have practically disappeared. The fact that its density, 3.7, as determined by Preston, coincides with the theoretical value just deduced is of interest.

Turning now to Fig. 4, six points indicated by circles have been marked along the coast-line of the eastern continent. Corresponding to these, six similar points have been marked along the American

[1] *American Journal of Science*, Vol. CXLV (1893), p. 256.

[2] *U. S. Geological Report*, 1882–83, p. 195.

coast. The two broken lines joining these various points are slightly inclined to one another, but the other small differences in relative position and distance are apparent and not real, being due to the necessary slight distortion of the map. The South American continent does not fit well into this arrangement, and does not appear to have remained perfectly parallel to North America during its transit across the fiery ocean, in obedience to the pull of the Moon. Instead, it seems to have rotated slightly, as shown, about a point somewhat to the east of the Isthmus of Panama.

In trying thus to match the continents together, we must take the outline of the continental plateau rather than the coast-line. Five-sixths of the area of the Altantic basin is thus very well accounted for, but there still remains a considerable area east of the United States, together with the Gulf of Mexico, and the Caribbean and Mediterranean Seas, not explained. The eastern outline of the Atlantic area is indicated by the dotted line.

The antipodes of the central spot in the map of the Pacific is indicated by the cross in northern Africa. If the ultimate releasing force which caused the disruption of the Moon was, as has been supposed, the solar tides, we should expect that a certain amount of material might escape from both sides of the Earth. If the Sun were overhead at the central point in the Pacific, then within less than an hour, using Darwin's rate of rotation, it would have been exactly opposite to the area in question in the Atlantic, Gulf, and Caribbean Sea.

The similarity of the Lesser Antilles to the Asiatic islands, already pointed out, corroborates this explanation. It is also to be noted that the greatest depths in the Atlantic, 21,000 feet, are found along the eastern boundary of this region. Similarly, one of the deepest parts of the Pacific, 31,000 feet, is indicated by the × close to the central point on the map, Fig. 1. Around this deep portion on the east, north, and west is a shallower area from 15,000 to 20,000 feet in depth, and then, as we approach the continents, again a deeper area.

All those who have studied the stratification of the Appalachian region have concluded that the sediments came chiefly from the east. Such extensive deposits require a larger land area than now exists;

in fact, one is needed of continental proportions. Whether these deposits are sufficiently ancient to be explained by the lunar hypothesis the writer is not prepared to say.

There are several coincidences relating to the position of the central point of the Pacific which may or may not be accidental. The close coincidence with the very deep area above noted is the first of these. The second relates to its latitude, $-25°$. This is within a degree and a half of the tropic of Capricorn. The tropics are the lines on a uniform sphere where the direct solar tidal pull acts for the greatest length of time on any particular area of rock. Here also the leverage of the tidal pull on the Earth's crust would be greatest in displacing a protuberant equatorial ring. If the Moon were generated from the Earth by centrifugal force, liberated by the tides, we should expect the central point to coincide with one of the tropics of that time. The coincidence with the present tropic would indicate that the axis of the Earth can have changed very little in the meantime. The third and fourth coincidences are more likely to be accidental. The third is that the central point coincides in longitude with Bering Strait, where the two continents are supposed to have slipped past one another. The fourth is that the strait is almost exactly 90°, more accurately 91°, in latitude from the central point.

If the greater continents were split apart, we should by the same analogy conclude that Antarctica and Australia were drawn from the Indian Ocean; the former from the vicinity of the Cape of Good Hope, the latter farther east.

If it is true, as here suggested, that we owe our continents to the Moon, then the human race owes far more to that body than we have ever before placed to its credit. If the Moon had not been formed, or if it had carried away the whole of the terrestrial crust, our Earth would have been completely enveloped by its oceans, as is presumably the case with Venus at present, and our race could hardly have advanced much beyond the intelligence of the present deep sea fish. If the Moon had been of but half its present bulk or had been slightly larger than it is at present, our continents would have been greatly diminished in area, and our numbers decimated, or our lands overpopulated.

Connected intimately with the origin of the continents is the problem as to the cause of volcanoes, and why they are at present always situated near the sea. A point that is of the utmost consequence in its bearing on this question is the fact, noted by Charles Darwin, that active volcanoes are found only where the coast-line is rising. Clearly the same cause produces both effects.

A rising region, as pointed out by Dutton, must evidently be increasing its volume. This increase may occur either with or without an increase of mass. In the latter case the increase must be due to a rise of temperature. It has been shown that, if a part of the Earth's crust fifty miles in thickness were to have its temperature raised 200° F., its surface would be raised to the extent of 1,000 to 1,500 feet.[1] The Bolivian plateau has an elevation of two and a half miles. That of the Himalayas is about a mile higher. It is improbable that these elevations are due to this cause.

The alternative is that in the rising regions we have an increase of mass. If the mass were increased materially, it has been shown by Gilbert[2] that the hot subterranean region should yield to the added pressure, thus neutralizing the elevation. An added column of rock two miles in height could not possibly be supported. Apparently our last resort is to introduce some lighter material, such as water or steam. The pressure on the steam, if its temperature were above the critical point, would be so great that its density would be but little less than the equivalent extrapolated value for water. It might have one-fourth of the weight of an equal column of rock.

Liquid lava is full of water, and as the lava cools the water is expelled from it. The lava at Hilo, Hawaii, contains innumerable bubbles, indicating the presence of steam, which had been retained by it within its structure for many days, ever since it had left the crater of Mauna Loa, fifty miles distant.

Since volcanoes are intermittent in action, the charging process must still be going on at the present time; otherwise there would have been one long discharge in the distant past, which would have rendered all our present volcanoes extinct.

Since volcanoes are active only near the oceans, it has been sug-

[1] Judd, *Volcanoes*, p. 347.

[2] *Continental Problems of Geology*, Smithsonian Report, 1892, p. 165.

gested that the eruption is due to sea water that has entered by cracks in the Earth's crust and is subsequently discharged from the volcano. Volcanoes do discharge salt water, but the solid ingredients of the water do not occur in the same proportions that they do in the sea. Some of the sea salts are often found to be absent, while other salts are often found that do not occur at all in sea water. This fact, together with the inherent improbability that sea water should be sucked in at a low level and pumped out at a high one, renders this explanation improbable.

Another explanation of the universal presence of water in volcanic products is that it is derived from rain water, which has percolated down through the soil. This theory, however, does not account for the fact that volcanoes are always found near the sea. Neither of these theories account for the gradual elevation of the land in volcanic regions.

Since the process of charging volcanoes with steam is still going on, and since it appears that the necessary water is not derived from either the sea or the atmosphere, the only alternative seems to be that it comes from the heavy stony material forming the ocean beds, and does not come in appreciable quantities, at present, from the lighter material forming the continents. It is evident, however, that this lighter material is sometimes cracked, permitting the discharge to take place through it. This was the case with the extinct volcanoes in central Europe, and those near the Yellowstone Park and Arizona in this country. The volcanoes at present active in North and South America seem to rise from what was probably formerly the edge of the continental plateau.

The next question that arises is: From what depth does the lava come? Judged by its temperature at the vent, unless it becomes heated by friction, by compression, or by radio-activity, on its way to the surface, which seems improbable, it must have come from a considerable distance. The rate of increase of temperature with the depth varies in different parts of the world from 20 to 100 feet per degree Fahrenheit. It may fairly be taken near the surface at 100° per mile of depth. From its surface temperature, Bonney estimates[1] that "the lava is generally supplied from a zone situated

[1] *Volcanoes*, p. 284.

at a depth of from 20 to 25, or possibly to 30 miles, in the crust of the Earth." The total thickness of the crust has been estimated by Fisher[1] at 30 miles. These values agree very well with that just computed from the volume of the Moon.

Daubrée has shown[2] that water separated from a chamber filled with steam at a temperature of about 160° C. by a close, fine-grained sandstone, passed through the slab with ease, against the outward pressure of the steam. He also found that the facility with which the water found a passage was increased by heat. There is therefore no difficulty in understanding the transmission of water through hot rocks at considerable depths. Its presence, moreover, would tend to lower the melting-point of the rock, and make it more viscous.

A certain amount of water may even be transmitted in this manner down through the ocean floors; but when we consider that the transmitting medium consists of cold rock several miles in thickness, the water advancing against a constantly increasing pressure, it does not seem that the amount transmitted per year in this manner can be very large.

In our hypothesis explaining the origin of the continents, it was stated that they were composed of the crust which was either originally solid or else had already cooled sufficiently to become so. They had therefore expelled a large part of any water which they may originally have contained. The ocean beds at the time of the great catastrophe were liquid. They therefore absorbed all the water available, if indeed they were not already saturated with it. They had a much higher temperature, having come from a greater depth, and contained much more water at this period, than the continents, and, it is believed, have been giving it out as they cooled ever since.

Doubtless the hot bases of the continents have absorbed some water from the ocean beds as the latter cooled, and the expansion and diminished specific gravity thus caused would tend to elevate them in the vicinity of the oceans. This has occurred notably in the vicinity of the Pacific, the whole of whose coasts are at the present time in a state of elevation. We can understand also that the sys-

[1] Milne, *Seismology*, p. 120.

[1] *Geological Experiments*, Vol. I, p. 237.

tematic difference in material and density, extending over large areas, would render the boundaries of the continents more subject to cracks, with their resulting volcanoes and earthquakes, than other portions of the Earth's surface. A zone of territory subject to earthquakes extends around the Pacific.

As is known from its rigidity, the interior of the Earth as a whole is solid. There cannot even be at present a continuous liquid surface between the center and the crust. Beneath every active volcano, however, there must be an area from which its lava is derived. In some way, without doubt by the contraction of the Earth, this lava is caused to approach the surface, and on the way it gradually changes from a viscous solid to a viscous liquid. There are only two ways in which this change can take place: one is by an increase in temperature, the other by a decrease in pressure. The latter is probably the actual one.

Tangentially considered, the lower portions of what we may for convenience call the Earth's crust are in a state of compression, the upper portions in a state of tension. Radially all are in a state of compression. Between the upper and lower portions is a neutral surface of no tangential strain. When a crack caused by the tangential tension reaches this neutral surface, the viscous rock oozes up through it, becoming more and more liquid as it approaches the surface and the pressure is diminished. As it melts and is relieved of pressure, its density diminishes, and, if it finally reaches the surface, the erupted lava will continue to flow till the pressure at its source is reduced to equality with the hydrostatic pressure at the base of the crack. The larger the opening and the shorter the distance from the surface, the sooner will this equality of pressure occur, and the shorter be the duration of the eruption. The expansion of the bubbles of steam near the top of the crack diminishes the hydrostatic pressure, and their escape obviously causes the explosions usually noticed. The violent manifestations are therefore all generated near the surface, as is the case of a geyser.

The uprush and escape of all this material broaden the crack into a tube several hundred feet in diameter. After the lava has ceased to flow, the steam working its way up to the vent still keeps a somewhat narrowed passage open. It thus continues as a line of

weakness; and when the flow of steam and viscous rock from below on all sides toward the area of diminished pressure again increases this pressure beyond the breaking strength of the resisting material, the eruption will be renewed.

Volcanoes frequently lie along arcs of circles, which, if complete, would resemble the lunar *maria* both in size and shape. One of the most complete of these series of arcs has the China Sea for its center, while the volcanoes are found in the Philippines, Celebes, Java, Sumatra, the Malay peninsula, and southern China to the west of Canton. The diameter of this circle is 2,000 miles. The Japan and Bering Seas are similarly partly surrounded by incomplete arcs. The shape of the latter is decidedly elliptical.

THE DOUBLE CREST OF SECOND WATCHUNG MOUNTAIN.[1]

J. VOLNEY LEWIS
Rutgers College, New Brunswick, N. J.

Twenty miles west of the Palisades of the Hudson River rise the prominent ridges of the Watchung Mountains, which extend southwestward from a point ten miles north of Paterson, N. J., almost to Somerville, a distance of forty miles. The parallel ridges of these mountains are the outcropping edges of extrusive trap sheets imbedded in a series of red shales and sandstones which constitute the upper (Brunswick) member of the Newark system in New Jersey. In general these strata have an average northwesterly dip of 12 to 15 degrees. It has long been known, however, that the recurved ends of the Watchung Mountains swing around the extremities of the boat shaped Passaic Basin syncline, which has been cut off on the northwest by a fault along the border of the crystalline rocks of the Highlands.

The hook-shaped southwestern portion of Second Mountain (see maps, Figs. 1 and 2) is much broader than elsewhere and for a distance of seventeen miles the crest is distinctly double. This condition has been explained[2] as the result of a curved longitudinal fault parallel to the present outcrop of the trap sheet. While entirely consistent with the facts, so far as at present known, the probability of such a coincidence is so extremely small that, in the absence of positive proof of faulting, this hypothesis must be regarded as exceedingly doubtful.

It is the object of the present paper to explain the observed conditions upon an altogether different basis, and in a manner requiring no assumptions that are in any way improbable in the light of our present understanding of the geologic history of the region. For this purpose brief discussions are here given of (1) the facts requiring explanation, (2) the interbedded shale hypothesis, (3) the curved longitudinal fault hypothesis, (4) the hypothesis of double flow with

[1] Published by permission of the State Geologist of New Jersey.

[2] Darton, *Bull. U. S. Geological Survey No.* 67, p. 22; Kümmel, *Ann. Report Geol. Survey of N. J.*, 1897, p. 125.

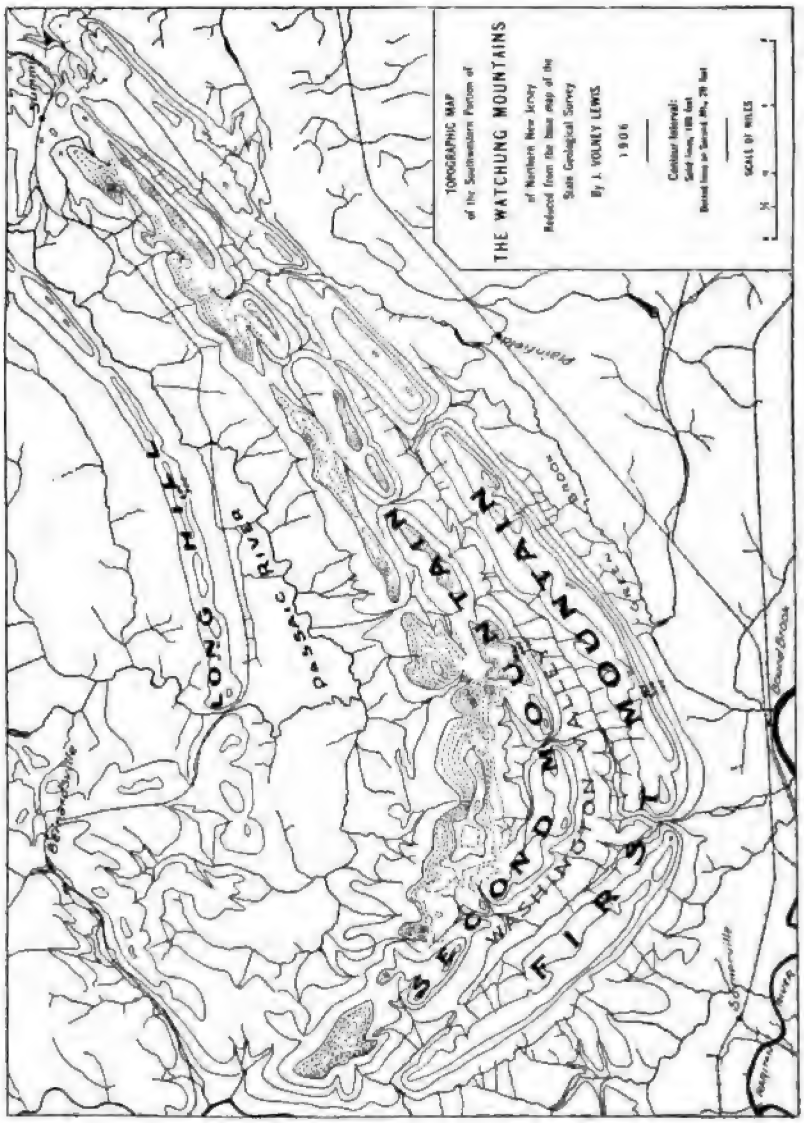

TOPOGRAPHIC MAP
of the Southwestern Portion of
THE WATCHUNG MOUNTAINS
of Northern New Jersey
Reduced from the base map of the
State Geological Survey
By J. VOLNEY LEWIS
1906
Contour Interval:
SCALE OF MILES
LONG HILL
PASSAIC RIVER
SECOND MOUNTAIN
FIRST MOUNTAIN
WASHINGTON VALLEY
GREEN BROOK
Plainfield
Somerville
Bound Brook

FIG. 1

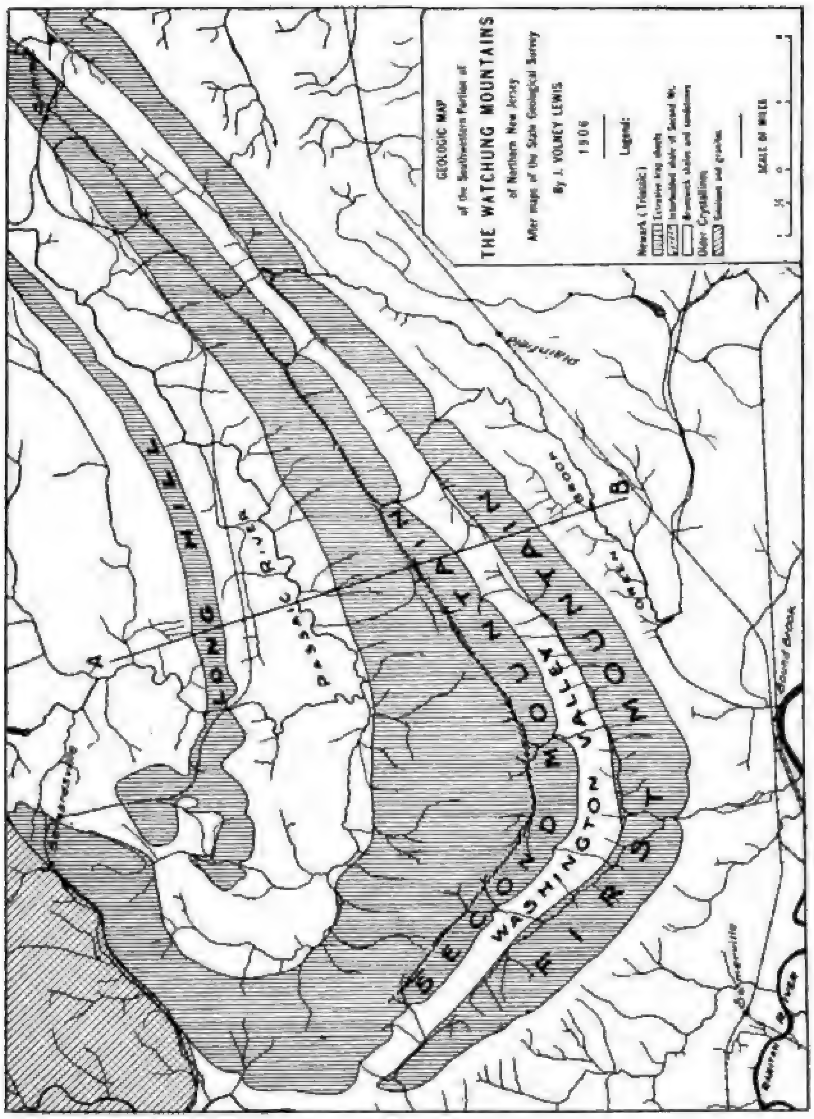

GEOLOGIC MAP
of the Southwestern Portion of
THE WATCHUNG MOUNTAINS
of Northern New Jersey
After maps of the State Geological Survey
By J. VOLNEY LEWIS
1906
Legend:
Newark (Triassic)
Older Crystallines
SCALE OF MILES
LONG HILL
PASSAIC RIVER
SECOND MOUNTAIN
WASHINGTON VALLEY
FIRST MOUNTAIN
GREEN BROOK
A
B

FIG. 2

intercurrent warping here advocated. The last is somewhat more fully presented and its bearings upon subsequent geologic history discussed. The others are summarized from Kümmel's report.[1]

1. *Conditions requiring explanation.*—The width of outcrop of trap along Second Mountain varies greatly. Along much of its course the crest is double, as pointed out above, and in the intervening valley shale has been found at a number of places either in wells or at the surface. At both ends of the ridge, however, the crest is single, and no shales appear within the trap area in the gorge of the Passaic River at Little Falls. In a well at Mount St. Dominic Academy, Caldwell, the following section was found: Glacial drift, 100 feet; trap rock, 775 feet; total 875 feet; shale at the bottom. A well bored for Mr. Keane on the inner crest of Second Mountain, near East Livingston, and but three miles from the well at Caldwell, furnished the following section: soil, 5 feet; trap rock, 90 feet; brown sandstone, 51 feet; trap rock, 381 feet; total, 527 feet. Both wells are in such location as to pass through an interbedded layer of sediments, if such existed. Over the country between the two crests Darton found red shale fragments which he regarded as portions of underlying sediments.

2. *The interbedded shale hypothesis.*—Kümmel considered the hypothesis that Second Mountain consists of two successive flows of lava separated by a stratum of sediments, but rejected it for the following reasons: (1) the crest is single at both ends of the ridge; (2) no trace of shale is found at either locality; (3) the gorge at Little Falls and the deep well at Caldwell show no shale. The "brown sandstone" reported from Mr. Keane's well he regarded as probably a red-brown variety of trap.

3. *The hypothesis of a "curved longitudinal fault."*—Under the seeming necessity of choosing between the interbedded shale hypothesis above referred to and that of a fault which possesses the remarkable property of conforming exactly with the present outcrop around the sharply recurved southwestern extremity of Second Mountain, both Darton and Kümmel accepted the latter, in spite of the fact that "no direct evidence of faulting beyond that furnished by the topography—the repetition of the beds—was found. . . . . Indirect

[1] *Loc. cit.*, pp. 125 ff.

evidence derived from a study of the width of the outcrop of the trap and the apparent thickness along different section lines" may be summarized as follows: On the assumption (1) that there was no deformation in the intervals between the various lava flows of the Watchung ridges (nor accompanying the flows); (2) that sedimentation was uniform throughout the area; (3) that the lava sheets are approximately of uniform thickness, their bases must have been originally parallel. Allowing for known faults this is still true of First and Second mountains; but from the base of the Second Mountain sheet to that of the third (Long Hill) is a distance that varies greatly in different sections, and the apparent differences are greater where the double crests of Second Mountain are most marked. This variation is ascribed to faulting which Darton assumed further to be confined to the areas of the present trap outcrop.

Kümmel points out several very obvious defects in the above reasoning: (1) that any or all of these various assumptions may be incorrect; (2) that there is no conclusive reason for supposing that faulting is restricted to the trap areas of the present surface; (3) that variations in thickness of either the trap of Second Mountain or of the overlying shales would vitiate the conclusions. Notwithstanding these elements of uncertainty and improbability, however, the estimates based on the above assumptions are regarded as "indicating quite clearly that some faulting has occurred," and as "strengthening the argument derived from the double crest." Hence the conclusion that "it is safe to assume that Second Mountain is traversed for much of its extent by a curved longitudinal fault."

4. *The hypothesis of double flow with intercurrent warping.*—The explanation here advanced is believed to be entirely consistent with all ascertainable facts and to be free from improbable assumptions. It is practically the interbedded shale hypothesis described above, freed from the restrictions of stability and uniform sedimentation in the intervals between the lava flows.

The present condition of the Newark rocks throughout eastern North America shows that they have been subjected to universal deformation, and as yet there has been discovered no means of defining the exact stage in their history at which the disturbing movements began. The slightest warping of the surface at any stage

of the sedimentation would have its inevitable effect upon the thickness and distribution of the subsequent deposits. This is particularly true of shallow water and continental formations, in one or both of which categories the Newark beds must be placed.

The proposed hypothesis to account for the conditions above enumerated in Second Mountain may be stated as follows: After the eruption of the trap sheet of First Mountain and the deposition of some 600 feet of overlying sandstones and shales, a second eruption occurred, forming a lava flow averaging probably 500 feet thick over the same region. This is the trap of the outer crest of Second Mountain. With this outflow began a gradual depression of the southern axial region of the great Passaic Basin syncline, the region northeastward from Somerville. In consequence of this warping, subsequent deposits were concentrated in this region, tending to build it up to the level of the adjoining area, but before this condition was finally attained deposition was again interrupted by eruption.

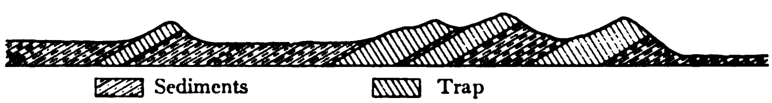


Fig. 3

Another lava sheet of about 500 feet average thickness was spread over the region, but not uniformly nor even approximately so, as the preceding flow had been. Over the shales in the area of subsidence the maximum thickness was at least 800 feet, while in the adjoining regions where it rested on the unburied flanks of the preceding flow it probably did not exceed 200 feet in thickness. Thus the two flows, separated by a brief interval of deposition, merged into one on the sides of the incipient syncline, but were elsewhere separated by a thin stratum of shale. (See section Fig. 3.) This refers, of course, to the portions of these sheets still preserved to us, all of which are involved in the Passaic Basin syncline.

When by later movements their upturned edges were exposed to the forces of weathering and erosion, the soft interbedded shales quickly wore away to a lower level, thus forming the continuous valley curving conformably with the outcropping edges of the adjacent trap sheets above and below. The valley between the crests of Second Mountain

is therefore considered to be exactly comparable to Washington Valley, between First and Second mountains. It is shallower and the escarpment of the overlying trap outcrop is less pronounced because of the limited thickness of the interbedded shales.

Evidence of continued depression in the same synclinal region is found in the sediments between Second Mountain and the overlying trap sheet of Long Hill. There is a decrease of one-fourth in the thickness of the intervening shales at Madison, as compared with those at Millington, and a much more rapid thinning out toward the west. The trap sheet of Long Hill is also thicker about Millington, but this may be due in part only to the original inequality of the surface upon which it was laid.

SECTION OF THE MANLIUS LIMESTONE AT THE NORTHERN END OF THE HELDERBERG PLATEAU

CHARLES S. PROSSER
Ohio State University

The Helderberg Mountains, or more properly plateau, form a prominent topographic feature of eastern New York the northern escarpment of which is very conspicuous to the south when traveling by electric or steam car between Schenectady and Albany.

Stratigraphic geology in America had its beginning in Albany and Schoharie counties, New York, so that for many years the Helderbergs have been classic ground for geologists. Near the northern end, about south of Meadowdale on the Delaware & Hudson railroad, a highway known as the Indian Ladder road climbs the steep escarpment and this section has been visited and studied by many geologists. Several years ago the writer described this section;[1] but at that time the limestones forming the conspicuous cliff were known as the Tentaculite and Pentamerus. It was attempted to separate these two formations according to the original definition of Gebhard and later description of Mather; but since the line of division was not very clearly indicated in the original description perhaps the writer was not altogether successful in locating the line of separation used by those early geologists. After the preparation of my paper, geographic names were substituted for those based upon the generic names of inclosed fossils and Vanuxem's "Manlius water-lime group," shortened to Manlius limestone, replaced the Tentaculite limestone, and the new name of Coeymans limestone was proposed to replace the Pentamerus.[2] Later, Professor G. D. Harris studied the Helderbergs and published a general section, "based largely on the outcrops near Indian Ladder," together with four special sections.[3] Mr. Christopher A. Hartnagel, assistant

[1] *Eighteenth Ann. Rept. State Geologist* [N. Y.], pp. 53–56.

[2] *Science*, N. S., Vol. X, Dec., 1899, pp. 876, 877.

[3] *Bull. Am. Paleontology*, No. 19, 1904, Pl. 1, and pp. 24–26.

geologist of the Geological Survey of New York, also studied the Indian Ladder cliff and sent me a detailed section from the top of the "Hudson River" sandstone to the base of the Coeymans limestone, and recently the writer spent a day in a re-examination of that part of the section. The typical section near Manlius has also been examined and after this study it is apparent that the line of division between the Manlius and Coeymans limestones in the Indian Ladder section ought to be drawn higher than it was in the section published by the writer in his article of 1901. This probable change was indicated by the writer in a footnote on p. 290 of Professor Amadeus W. Grabau's "Guide to the Geology and Paleontology of the Schoharie Valley in eastern New York."[1]

The following section is based to some extent on one furnished by Mr. Hartnagel, but it has all been remeasured and verified by the writer and on account of the importance of the Helderberg section in geological literature it is considered worthy of publication.

No.		Thickness of Zone—Feet	Total Thickness—Feet
13.	Bluish-gray, coarser-grained limestone than the subjacent beds which is limited at the base by a rather marked bedding plane. In the lower 1½ feet Mr. Hartnagel reported *Strophonella punctulifera* (Con.) Hall, *Spirifer vanuxemi* Hall, and *Leperditia alta* (Con.) Hall. *Gypidula galeata* (Dal.) H. and C. appears above the 1½-foot zone and within 5 feet becomes abundant. At the base is a coral resembling *Cyathophyllum*. The lower 2 feet of this division Professor Harris called "Transition layers,"[2] and this name for the zone is quite appropriate since, lithologically, the rock is bluish-gray in color and coarser grained than the subjacent Manlius limestone; but on the other hand it contains *Spirifer vanuxemi* Hall and *Leperditia alta* (Con.) Hall, which are generally considered as characteristic of the Manlius limestone, while	36+	95+

[1] *New York State Museum, Bull.* 92, 1906, 386 pages, 225 figs., 24 pls., and "Geologic Map of the Schoharie and Cobleskill Valleys." This comprehensive handbook on the geology of the Schoharie valley and northern Helderbergs will prove of inestimable value to students of this classic region.

[2] *Bull. Am. Pal.*, No. 19, p. 25.

No.		Thickness of Zone—Feet	Total Thickness—Feet
	Gypidula galeata (Dal.) H. and C., the characteristic fossil of the Coeymans limestone, was not noted until just above this zone. In this cliff it is evident that the line of division between the Manlius and Coeymans limestones is not sharply marked. The most clearly marked physical change is at the above-noted bedding plane, where Mr. Hartnagel prefers to draw the line of division between these two formations which, in some respects, appears to be the most satisfactory line of division. In the Indian Ladder highway cut from this bedding plane 36+feet of Coeymans limestone was measured.		
12.	*Manlius limestone*.—From this horizon the subjacent rock undoubtedly belongs in the Manlius. At the top is frequently a blue, thin-bedded limestone about 6 in. thick, which contains *Leperditia alta* (Con.) Hall. The color is dark blue like that of the Tentaculite limestone. This is No. 2 of Professor Harris' section. Below is a Stromatopora bed which, on the cliff some rods to the east of the "ladder," varies in thickness from 1½ to 2½ feet. This is No. 3 of Professor Harris' section which is 3.1 feet in thickness where he measured it, a quarter of a mile west of the "ladder," while in the cut on the highway 4 feet was obtained and *Spirifer vanuxemi* Hall was noted.	3±	59±
11.	Dark blue, somewhat irregularly bedded limestone, the lower part of which is generally quite massive, but the upper 1½ to 2 feet is thinner bedded and contains *Leperditia alta* (Con.) Hall. The thickness of this zone varies along the cliff from 5 feet, some distance east of the "ladder," to 5½ feet in Hartnagel's section, 6 feet in Harris', where it is No. 4, and 6½ feet in the highway cut. The most conspicuous lithologic break in this portion of the cliff occurs at the base of this zone; but the color of the rock and its fauna ally it more closely with the Tentaculite than the Pentamerus limestone.	6	56

No.		Thickness of Zone—Feet	Total Thickness—Feet
10.	Cement beds which are compact, even bedded, and generally weathered back a foot or two, and sometimes several feet within the face of the cliff. This zone, as a rule, is conspicuously shown on the face of the escarpment. Its thickness is somewhat variable, ranging from 4 feet, 9 inches, at the first spring east of the highway to 3 feet in Harris' section. It is given as $4\frac{1}{2}$ feet by Hartnagel and on the Indian Ladder road it is 3 feet, 9 inches. In my former paper this zone formed the upper part of what was termed the transitional beds from the Tentaculite to the Pentamerus limestone; but it was included in the Tentaculite limestone. They were termed transitional because *Tentaculites gyracanthus* Eaton, the characteristic fossil of the Tentaculite limestone, was not found in them, while some of the other Tentaculite fossils were found well toward their top and the marked lithologic break at the top of the cement zone was thought to represent the line of division between these two limestones as used by the older geologists. At the base of the cement rock is generally a shaly limestone, about 6 inches thick, which frequently shows ripple marks. The distance from the top of this zone to the base of the Manlius limestone may be easily measured in the cliff near the first spring east of the Indian Ladder road.	$4\frac{5}{6}\pm$	50 −
9.	Massive rough limestone containing Stromatopora in which Mr. Hartnagel reported *Spirifer vanuxemi* Hall and *Leperditia alta* (Con.) Hall.	5	$45\frac{1}{6}$
8.	Thin-bedded limestone with Stromatopora layer at base. These two zones correspond to No. 6 of Harris' section with the same thickness.	4	$40\frac{1}{6}$
7.	Massive compact layer.	3	$36\frac{1}{6}$
6.	Thin-bedded, dark-blue limestone which has a metallic ring. Many of the layers contain immense numbers of *Tentaculites gyracanthus* Eaton.	$22\frac{1}{3}$	$33\frac{1}{6}$
5.	Thick and thin layers of dark-blue lime-	$6\frac{1}{2}$	$10\frac{5}{6}$

No.		Thickness of Zone—Feet	Total Thickness—Feet
	stone with a thickness of 6½ feet and perhaps it it may reach 7½ feet. A massive layer near the middle of this zone, according to Mr. Hartnagel, contains abundant specimens of *Modiolopsis dubius* Hall and *Leperditia alta* (Con.) Hall while *Spirifer vanuxemi* Hall is common. The base of this zone marks the bottom of the Manlius limestone with a total thickness of 54½+ feet in the above section.		
4	Soft seam of shaly, much-decomposed material about ½-inch thick. This layer appears all along the exposure at the first fall and the second spring west of the "ladder." The overlying layers are all regular, so that this one marks a change in deposition and, apparently, a formational line of division.	½ in.	4⅓+
3.	Dark, contorted, seamy limestone with appearance of gypsum rock which, on examination, Mr. Hartnagel reports to be a sandy limestone with some clayey material; but no gypsum. This zone has a variable thickness and is more or less irregular.	10+in.	4⅓
2.	Layer containing much pyrite and many seams of calcite, where pyrite is abundant, weathering to a dirty yellow color. The rock contains frequent cavities, is broken, or has irregular structure.	3½ ft.	3½
1.	"Hudson River" sandstone, thickly bedded and very quartzose at top, dark olive-gray color, with pyrite scattered through the rock in small crystals.		

In my former section the rocks corresponding to Nos. 2 and 3 of the above section were referred to the Waterlime (Rondout)[1] which was accepted by Professor Schuchert in his discussion of the same section.[2] Professor Harris, however, stated that at this locality "there are four or five feet of gypsiferous and pyritiferous shales, resembling in many ways the Salina beds beneath the Cobleskill

[1] *Eighteenth Ann. Rept. State Geol.* [N. Y.], p. 54.

[2] *Am. Geol.*, Vol. XXXI, 1903, p. 172.

at Howe's Cave."[1] Mr. Hartnagel carefully examined these beds, failed to find gypsum, stated that the association is quite different from that of the pyrite layer (Salina) at Howe's Cave, and concluded that it was more in harmony with known facts to refer these layers (Nos. 2 and 3) to the Rondout.

The Manlius limestone is regarded as beginning with the base of No. 5 and extending at least to the top of No. 12, and perhaps a foot and a half higher, with a total thickness of 54½+feet. This thickness is 8½ feet greater than the sum of the Tentaculite and transitional beds as given in my paper of 1901, due to the addition of Nos. 11 and 12 of the above section which have a united thickness of about 9 feet. If to the 54½+feet which I have given as the thickness of the Manlius there be added the overlying transition layer of Harris, which he gives as 2 feet, then the thickness of the Manlius limestone will become 56½+feet and the measurements of Harris and myself identical in the Indian Ladder cliff.

The thickness of the Pentamerus limestone in the 1901 paper was given as from 49 to 52 feet along the Indian Ladder cliff and subtracting the lower 9 feet, which is now put in the Manlius, there remains between 40 and 43 feet for the Coeymans limestone.

It is also probably true that in the Countryman Hill section by Prosser and Rowe[2] a similar 9 feet ought to be taken from the base of the Pentamerus limestone and added to that of the Tentaculite to make the total thickness of the Manlius limestone, in accordance with the section of that hill given by Professor Harris.[3] The writer has not been able to re-examine this section, but if the above change be made then the thickness of the Manlius limestone in the Prosser and Rowe section will become 55 feet and that of the Coeymans limestone, 41 feet.

[1] *Bull. Am. Pal.* No. 19, p. 25.

[2] *Seventeenth Ann. Rept. State Geol.* [N. Y.], 1899 [1900], pp. 329–42.

[3] *Bull. Am. Pal.*, No. 19, p. 26.

NOTE ON THE RED BEDS OF THE RIO GRANDE REGION IN CENTRAL NEW MEXICO[1]

WILLIS T. LEE

During the summers of 1904 and 1905 the writer was engaged in geologic investigations in the Rio Grande valley in central New Mexico. The results will be set forth in detail in the near future, but a preliminary statement is here given of certain facts which throw some light on the complex problems of the Red beds.

There are exceptional opportunities for geologic observations in the Rio Grande valley. The region is one in which many monoclinal or block mountains occur, having precipitous, scarp-like faces in which the various geologic formations, ranging in age from pre-Cambrian to Quaternary, are conspicuously exposed. The Red beds here described outcrop at the surface with minor interruptions from Galisteo Creek at the southern end of the Rocky Mountains, southward to Rincon, a distance of about 200 miles. They were examined with care in many places east of the Rio Grande, notably in Galisteo canyon; at the northern end of Sandia mountains; in Abo canyon east of Belen; in the mountains east of Socorro; in San Andreas mountains east of Engle; and in the Caballos-Fra Cristobal range north of Rincon.

Throughout this distance the Red beds are uniform in character, consisting usually of three more or less distinct divisions. The lowest division is composed principally of massive, dark red sandstone, with a maximum observed thickness of about 800 feet. The middle division consists of pink and white shale and gypsum, with a subordinate amount of limestone. The limestone is not always present, and the gypsum varies in thickness. In some places, as in Galisteo canyon at the northern end of the region, the massive gypsum is about 140 feet thick, with the accompanying shale inconspicuous and the limestone practically absent. In other places the gypsum is distributed in thin beds through a considerable thickness of shale

[1] Published by permission of the Director of the U. S. Geological Survey.

and limestone, as is the case in San Andreas Mountains east of Engle, where the gypsiferous division is nearly 1,000 feet thick. The upper division, consisting of alternating layers of yellow, pink, and white sandstones and shales, has an observed thickness of many hundreds of feet, but is not always clearly differentiated from the middle or gypsiferous division.

The Red beds of the Rio Grande region are similar in general appearance and lithologic character to the red sandstone formation occurring along the eastern base of the Rocky Mountains, and extending thence eastward across southern Colorado and New Mexico. In other words the red sandstones and shales of the Rio Grande region form part of the complex which is frequently called "the Red beds" of the Rocky Mountain region.

In the Rio Grande region the Red beds rest unconformably upon an extensive series of Upper Carboniferous limestones. At the base of the red strata occurs a limestone conglomerate, the pebbles of which contain fossils identical with those of the limestones upon which the conglomerate rests. This was observed in the hills east of Socorro, in Abo canyon east of Belen, and at the northern end of Sandia Mountains. Twenty-five to seventy-five feet above this basal conglomerate occurs a persistent limestone member containing a rich fauna. Collections were made from this limestone in several localities.

Many of the limestones of the middle or gypsiferous division are also very fossiliferous, and large collections were obtained from them in widely separated localities. The upper division, so far as observed, is sparingly fossiliferous, and not faunally different from the underlying or middle division. But overlying it in the southern half of the region occurs a limestone several hundred feet thick, which yielded an abundant fauna. This overlying limestone is absent in the northern part of the region, but occurs in the central part and apparently thickens toward the south. It is well-developed in the mountains east of Socorro, in the San Andreas Mountains east of Engle, in the Caballos-Fra Cristobal Range, and elsewhere. On account of its important bearing on the age of the underlying Red beds, fossils were collected from it in about thirty separate localities.

The fossil collections from the various horizons are too voluminous

to be described in this note, and discussion of them is reserved for the more extended report to follow. Dr. G. H. Girty,[1] of the Geological Survey, who has examined them, states that the faunas from the Red beds are Upper Carboniferous, although they are sharply distinct from those of the underlying limestones which are also Upper Carboniferous. He states further that the fauna of the limestone overlying the Red beds is also clearly Carboniferous and probably older than the Guadalupian fauna. In other words, all of the 2,000 feet or more of the Red beds just described in the Rio Grande region are Carboniferous, and probably older than the Guadalupian or so-called Permian of western Texas.

No red sediments were observed immediately overlying the uppermost Carboniferous limestone. In some of the southernmost exposures, particularly in the Caballos Mountains, this limestone is overlain by dark-colored shales in which Benton fossils[1] were found about 200 feet above the Carboniferous limestone.

At the northern end of the region in Galisteo canyon the triple division of the Carboniferous Red beds is characteristically developed, although the exposed thickness is much less than it is farther south. Only the upper 250 feet of the lower or massive sandstone division is exposed. The gypsum is here about 140 feet thick; and the upper or pink division, consisting mainly of sandstone, is 300 feet or more in thickness. No fossils were found in the Red beds at this place, but large collections were obtained from the lower division near Tejon, about 12 miles south of Galisteo Creek.

The limestone which overlies the pink sandstones in the southern part of the region, and which has just been described as the highest horizon at which Carboniferous fossils were found, does not occur in Galisteo canyon. About 200 feet of variegated shales and sandstones, having the same general appearance as the Morrison formation, overlie the pink sandstones and are separated from them by what appears to be an unconformity of erosion. This was seen in only one place. The variegated shales are overlain by a massive white friable sandstone about 60 feet thick and similar in appear-

[1] Personal communication.

[1] The Cretaceous fossils referred to here and elsewhere in this paper have been identified by Dr. T. W. Stanton.

ance to the sandstone which, in eastern Colorado and New Mexico, has frequently been called the lower Dakota, but which, as Stanton[1] has shown, underlies fossiliferous Comanche in the plains region, and in the foothills of the Rocky Mountains at Canyon City, Colo. This sandstone is followed in turn by fossiliferous sandstones, shales, and limestones representing the principal subdivisions of the Upper Cretaceous section of the eastern Rocky Mountain region, with the possible exception of the Dakota.

In the central part of the region described, although known Carboniferous Red beds were observed in several places with fossiliferous Benton in the same section, no red sediments were observed which could be referred to the Triassic. This fact is significant, since Triassic Red beds are known to occur in the Gallinas Mountains,[2] about 60 miles northwest of Galisteo canyon, and in the plains region of eastern Colorado and New Mexico. Triassic vertebrates have been reported by Darton[3] in the Red beds of Purgatory canyon in southeastern Colorado, and by Stanton[4] in the Rio Cimarron canyon of eastern New Mexico. The writer has also found them in the northern breaks of the Staked Plains in eastern New Mexico.

The latter occurrence has not heretofore been described. The fossil bones were found at E. O. Davis' ranch, about 20 miles southeast of Tucumcari. They occur at the top of the Red beds, overlain at this point by plains-Tertiary, but covered half a mile farther north by yellow sandstones and shales containing *Gryphaea corrugata* Say and other characteristic Comanche fossils.

Invertebrates of probable Triassic affinities have been reported from the red beds of the Canadian valley by Stanton,[5] who in company with the writer obtained a collection of them at Henry Hunikes ranch on the Rio Concho, about 30 miles southeast of Las Vegas.

[1] T. W. Stanton, "The Morrison Formation and Its Relations with the Comanche Series of the Dakota Formation," *Journal of Geology*, Vol. XIII (1905), pp. 657–69.

[2] E. D. Cope, *Monographs*, U. S. Geographical and Geological Surveys West of 100th Meridian, Vol. IV, Part II, "Report upon the Extinct Vertebrata Obtained in New Mexico by Parties of the Expedition of 1874, 1877," pp. 5–13.

[3] N. H. Darton, "Preliminary Report on the Geology and Underground Water Resources of the Central Great Plains," U. S. Geological Survey, *Professional Paper No. 32*, 1905, p. 159.

[4] *Op. cit.*, p. 665.

[5] *Ibid.*, p. 666.

The shells occur about 500 feet below the top of the Red beds as exposed in the Canadian escarpment 5 miles to the west. Stanton[1] states that the collection contains two species belonging probably to the genus *Unio* and comparable, though apparently not identical, with the species of *Unio* described by Meek from the Triassic of Gallinas Creek, New Mexico, and by Simpson from the Dockum beds in western Texas. Regarding the age relations of these invertebrates, Stanton states that "the occurrence of *Unio* in these Red beds is considered sufficient evidence of their post-Paleozoic age, from the fact that the genus is not known to range elsewhere below the Mesozoic, and, with the exception of these forms described by Meek and Simpson, it has not been recorded in beds older than the Jurassic."

Since the Red beds at no great distance both east and west of the Rio Grande region are in part at least Triassic, it is somewhat surprising that all of the 2,000 feet or more of the Rio Grande Red beds (except the late Cretaceous red series described below) should prove to be older than the Permian. It is possible that further investigation may reveal the presence of younger Red beds in localities not yet examined in the Rio Grande region, but, judging from the evidence at hand, it is more probable that, in case Triassic and Permian beds were ever deposited in this region, they were eroded away prior to the deposition of the Upper Cretaceous sediments.

A second or younger red series occurs in the Rio Grande valley which has sometimes been confused with the Carboniferous Red beds just described. It is perhaps best exposed near Elephant Butte, west of Engle, N. M., where it consists of shale, sandstone, and conglomerate more or less highly colored and several hundred feet thick. It is well exposed only where the Rio Grande and its tributary streams have eroded into it between the Caballos and Fra Cristobal Mountains. It is exposed close to a zone of intense faulting, and probably for this reason has been erroneously interpreted as a part of the older or Carboniferous Red beds brought to the surface by faulting.

The red sediments at Elephant Butte are very similar in general appearance to the Carboniferous Red beds, and might be easily mistaken for that formation until examined closely, when they are

[1] Personal communication.

found to differ in composition from the older beds and to lie stratigraphically above fossiliferous limestones and shales of Upper Cretaceous age. At the northern end of Caballos mountains, two miles south of Elephant Butte, the Upper Carboniferous formations, including the older Red beds, together with their underlying and overlying limestones, occur overlain by fossiliferous strata of the Benton formation, which in turn is followed by an extensive series of Cretaceous sandstones, containing beds of coal at its base, and great quantities of fossil wood at higher horizons. The leaves and tree trunks of both monocotyledonous and dicotyledonous varieties are numerous. Palm wood is particularly abundant.

The red sandstones and shales constitute the uppermost exposed member of the coal-bearing sandstones and, in addition to the fossil plants, contain Dinosaur bones. No excavations were made in order to secure satisfactory material for specific determination, but Mr. J. W. Gidley, of the National Museum, who examined the collections, states that the Dinosaurs belong to the genus *Triceratops*, clearly indicating that these red beds are of late Cretaceous age.

A similar series of red sandstones and conglomerates occurs at the northern end of the region, and was observed above the coal-bearing sandstones near Cerillos, and again near the Hagan coal-fields, a few miles south of Cerillos. In both of these localities the red sediments occur at the top of the Upper Cretaceous section and contain great quantities of petrified wood, but are otherwise unfossilferous, so far as known.

The conglomerates of this formation are made up of pebbles, of various igneous and metamorphic rocks, together with limestones containing Carboniferous fossils, and red sandstones similar to those of the older or Carboniferous Red beds. Many of the pebbles are only slightly rounded and were apparently transported but short distances. The upper part of the formation, throughout an exposed thickness of about 200 feet near Hagan, is a conglomerate composed mainly of fragments of andesite.

This formation was originally described by Hayden[1] as the Galisteo sands. On account of the strong resemblance in physical character,

[1] F. H. Hayden, *U. S. Geological Survey of the Territories* for 1867, 1868, and 1869, reprint 1873, p. 166.

stratigraphic position, and general appearance, the Galisteo formation is here regarded as probably a time equivalent of the Triceratops or late Cretaceous red beds of the Elephant Butte region.

In concluding I would emphasize the fact that there are two red formations in the Rio Grande region, which resemble each other so closely in places that careful observation is sometimes necessary in order to distinguish between them; and that neither of these formations belongs to the Jura-Trias or Permian, to which they have frequently been referred, the older one belonging to the Pennsylvanian system, and the younger one to the Upper Cretaceous.

U. S. Geological Survey, Washington, D. C.,
June 28, 1906

STUDIES IN THE DEVELOPMENT OF CERTAIN PALEOZOIC CORALS

G. E. ANDERSON
Columbia University, New York

ON THE ORIGIN AND DEVELOPMENT OF THE INNER WALL

Certain Paleozoic corals have been characterized by their authors as containing an inner wall which divides the corallite into an inner central and an outer annular area, the latter extending between the two walls. It has also been observed that in a number of these genera the septa extend to the center, penetrating the supposed inner wall, while in others the septa terminate in the inner wall itself. The genus Acervularia is a type of the former and Craspedophyllum[1] of the latter. The character of the inner wall in the two types is such that they can readily be differentiated even in a very cursory examination. While both genera have been considered to contain an inner wall, Edwards and Haimes as early as 1850 (*Polyp. Foss. des Terr. Paleoz.*) differentiated the two types by noting that the internal structure of Eridophyllum, which is of the Craspedophyllum type, differed from Acervularia in that the septa terminated in the inner wall, while in the latter the septa extended through the inner wall into the inner central area. They do not record having noted any difference in the structure of the inner walls themselves in the two genera.

Thin sections reveal the fact that the structure of the two types of wall are quite different and that they have an entirely different origin. The inner wall in the Craspedophyllum-Eridophyllum type is of a similar nature in texture and thickness to the septa, and occupies but a small central circular portion of the corallite.

In Craspedophyllum the diameter of the inner wall is about one-sixth to one-fifth that of the corallite. In the normal adult of this genus the inner wall has one opening, connecting the central area with the cardinal fossula. This gives to the inner wall the shape

[1] Equivalent to Thomson's Crepidophyllum, which term is used by Canadian paleontologists.

of a horseshoe, but in more specialized individuals a bridge spanning the cardinal fossula gives the inner wall a circular outline and completely separates the inner circular and the outer annular areas.

In the Acervularia type[1] the supposed inner wall is much thicker than the septa and in size about one-half the diameter of the corallite, so that even the tertiary septa take part in its formation and these as well as the secondary septa may extend into the inner central area. The supposed inner wall thus formed is not of uniform thickness, being thicker at the intersection of the septa: in some individuals the thickening from each septum is not sufficient to be in contact with the thickening from the neighboring septum, thus giving a number of openings in the wall. This is readily accounted for when it is seen that the apparent wall is formed by the lateral thickening of the septa at or near the end of the tertiary septa. When sufficient thickening of the septa occurs, they will be brought in contact, giving the appearance of an inner wall. It is evident that the supposed inner wall of this type is rather of the nature of a pseudotheca, the portion of the septa between the region of the septal thickening and the outer wall corresponding to the costae, thus differing greatly from the corals containing a true inner wall.

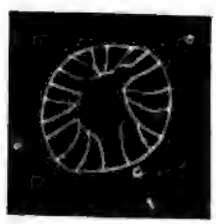


FIG. 1.—Cross-section of a young corallite of *Craspedophyllum subcaespitosum* Diameter 2^{mm}. *a*. The alar septa. *c*. The cardinal septum. Showing the early grouping of the septa. Four openings are shown but the normal condition is three, the two alar and the one at the cardinal fossula.

We may now inquire into the nature of the inner wall itself as present in such a genus as Craspedophyllum. The Devonic species, ***Craspedophyllum subcaespitosum***, from the Hamilton of Thedford, Ontario, is here chosen, as it is one which is especially distinguished as showing the typical structure of the true inner wall.

The mode of origin and development can be understood by comparing a series of figures (Figs. 1–5) representing the development of the inner wall

[1] This refers to description of the type of Acervularia. In some specimens of Acervularia in this country there is no lateral thickening of the septa, and hence no indication of the supposed inner wall.

as revealed in successive sections of a single corallite. It is seen that each alar region is that at which new septa are successively added to the primary septa (Fig. 1).

The addition of new septa takes place in such a manner that the new short septa are inclined toward the older, with which they are permanently fused with their inner borders, never being detached even in the most developed stages. It is to this persistent fusion of the inner borders of the long septa that the inner wall is directly due, as will be explained presently. It is evident that the addition of new septa is the same as Duerden has found to be true in the genus Streptelasma (*Biological Bulletin*, Vol. IX, No. 1, p. 30), but that genus differs from Craspedophyllum in that the septa become free toward the close of development. It differs from the genus Hadrophyllum, as in the latter the alar pseudofossulae[1] and the pinnate arrangement of the septa are maintained in the most developed stages, whereas in Craspedophyllum the alar pseudo-fossulae become obliterated very early in the life of the individual by the formation of a dissepimental bridge, and the pinnate arrangement of the septa, with the exception of one or two septa on either side of the cardinal fossula, gives place to the more specialized radial arrangement.

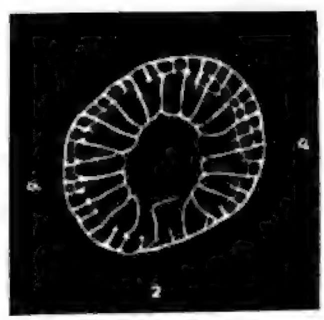


FIG. 2.—Section of same corallite 5^{mm} higher up. Diameter 3^{mm}. *a*. The alar septa. The cardinal fossula is connected with the inner central area.

The growth of septa in the early stages is very rapid, but the central area is always left intact never being invaded by them. This gives the septa an irregular appearance which greatly adds to the difficulty of detecting the Streptelasma mode of arrangement; the difficulty being further augmented by the tendency of the septa to arrange themselves radially and yet to remain attached with their inner borders. It is evident, that, for the septa to remain attached in this manner, only the peripheral portion can become radial at first, but this portion gradually extends inward until

[1] Grabau and Shimer, *North-American Index Fossils*, p. 48.

finally it reaches a point where it will be nearly at right angles to the inner part or attached border, which is at this time about parallel in position to the outer wall. This inner portion of each septum in this manner forms a part of the inner wall as fast as the septa become radially directed (Figs. 2, 3).

In a later section (Fig. 2) the alar pseudo-fossulae have been spanned by a dissepimental bridge which is here slightly thinner than the normal width of the inner wall. The inner wall ends in two septa, one on each side of the cardinal septum as would be expected, unless the latter should take part in the formation of the inner wall which, however, has not been observed.

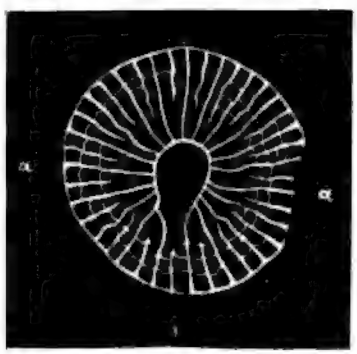


FIG. 3.—Section of same corallite taken 5^{mm} higher up than section of Fig. 2. *a*. The alar septa. Diameter of corallite, 4^{mm}.

In a section of a later stage (Fig. 3) the inner wall is of uniform thickness and ends in the septa nearest the cardinal fossula, as in Fig. 2. The neck between the cardinal fossula and the inner central area has become more narrow. The cardinal septum has been reduced in size to that of a tertiary septum.

This mode of development of the inner wall extends from the alar septa as initial points towards the cardinal region, and simultaneously from either side of the counter septum as another initial point toward the two alar regions. There would, therefore, be a break in the inner wall in the region of the cardinal septum, and two breaks, one at each of the alar regions where growth from the counter quadrants ceased. The two latter are early spanned by the deposition of material of a similar nature to that of the septa, thus uniting the groups and making the septal structure more firm. In Fig. 2 this growth is in the course of construction and is completed before the stage in Fig. 3 is reached, as here the wall is of uniform thickness throughout—and the "bridges" spanning the pseudo-fossulae in Fig. 2 are thoroughly incorporated. This eliminates the last trace of the

alar pseudo-fossulae, and all the septa have assumed their complete radial direction with the exception of one on either side of the cardinal fossula.

The opening in the inner wall in the region of the cardinal fossula is very persistent and remains permanently in normal individuals of the species, constituting the character of the horseshoe shaped inner wall of Craspedophyllum (Fig. 4.) In normal types it persists into the adult, but in the last stages of accelerated types it is closed. While this opening remains, the two septa on either side of the cardinal septum remain pinnate and form the ends of the incomplete wall (Fig. 3). The septa very slowly arrange themselves radially and in a similar manner to the earlier ones contribute their portion to the ends of the inner wall (compare Figs. 3 and 4). The septa on either side of the cardinal septum are now more radially arranged than in Fig. 3, and the connection between the inner central area and the cardinal fossula is more constricted. It is seen in Fig. 4 that as these two septa become radially directed, the neck connecting the cardinal fossula with the inner central area is gradually constricted until a stage is reached, as shown in Fig. 5, when this neck is spanned by a similar dissepimental bridge which early in the life of the individual cut off the connection between the alar pseudo-fossulae and the inner central area. It is evident that in further development of the individual, the cardinal fossula cannot be distinguished and to all appearance becomes similar to one of the interseptal spaces. The septa on either side of the cardinal septum have now assumed a nearly radial direction and the dissepimental bridge spans the cardinal fossula making the inner wall complete. In Fig. 5 one can clearly trace the

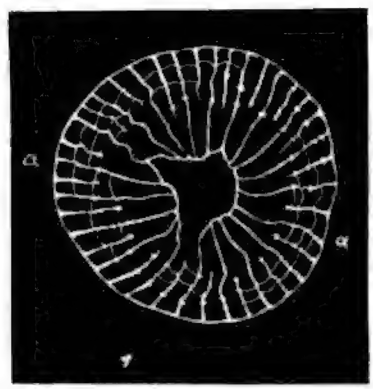


FIG. 4.—Cross-section of the same corrallite taken 5^{mm} higher up than Fig. 3. Diameter 4^{mm}. *a*. The alar septa. A slight irregularity of growth on the left.

order of development of the septa by their inner borders retaining a slight indication of the pinnate arrangement in the early stages. Further development of the corallite will tend to make the septa perfectly radial in direction and the inner wall, to which the primary and secondary septa are still firmly fused, assume a circular outline which is better illustrated in more specialized individuals than is shown in Fig. 5. At such a stage the true relation which exists between the inner wall and the long septa is not so evident. The former now develops quite independently of the septa, the inner borders of which may be considered as fused with the inner wall itself. The inner wall becomes circular at this stage, and it is evident that the cardinal fossula is no longer prominent. The cardinal septum has been reduced in size so as to be equal in length to a tertiary septum.

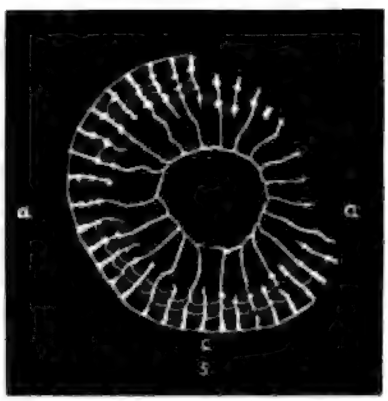


FIG. 5.—Cross-section of same corallite taken 2^{mm} above section of Fig. 4. *a*. The alar septa. *c*. The cardinal septum. Diameter 5^{mm}.

The tertiary septa do not appear until the secondary septa are well developed (Fig. 1. shows no tertiary septa). These differ from the primary or secondary septa in being radially arranged from their first appearance in the outer wall, and consequently their inner borders are free and can, therefore, easily be distinguished from the secondary septa. They extend one-half the distance to the inner wall before the latter is closed in the region of the cardinal septum, and this constitutes their full growth.

So far only the transverse sections at different stages have been discussed, though the longitudinal section (Fig. 6) is equally interesting. The central area is occupied by a series of tabulae the outer borders of which are fused in the inner wall, which is circumscribed by a second series of tabulae distinguished from the first series in being more delicate and more crowded. The second series of tabulae are fused with their inner borders in the inner wall, but have no con-

nection with the first series. Their outer borders extend to the innermost series of interseptal dissepiments and these dissepiments occupy the remainder of the interior to the outer wall. The carinae appear, at irregular intervals, as parallel bars extending inward and upward in an arching manner.

The essential characteristics, with the exception of the completed inner wall, are more specialized in the species *C. archiaci* from the Hamilton of Thunder Bay, Michigan. In a single corallum are found individuals representing the several stages of development. Thus are found individuals, in the young stages of which the inner wall has not appeared, others in which it is open at the cardinal septum, and still others in which it is completely closed, which is a rarer feature in this species than in *C. subcaespitosum*. When the inner wall is incomplete, the cardinal septum often extends into the inner central area (Fig. 7). This peculiarity has not been observed in any other species containing a true inner wall. When the wall is completely closed in this species, the cardinal septum extends to the dissepimental bridge which spans the cardinal fossula, becoming identical with a secondary septum with tertiary septa separating it from the other secondary septa.

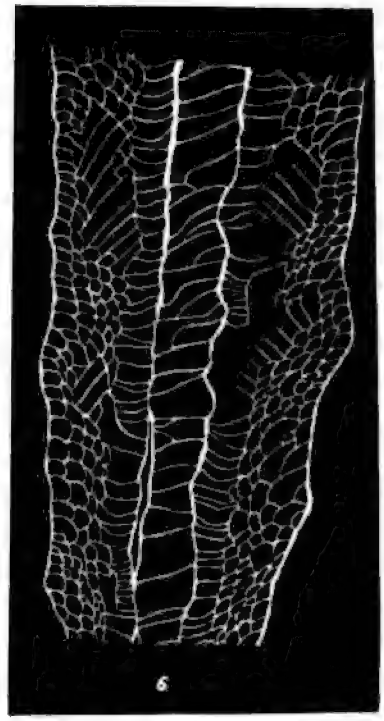


FIG. 6.—Longitudinal section cf *Craspedophyllum subcaes pitosum* showing the slight tapering of the corallite; and, from the margin toward the center: the interseptal dissepiment; the carinae; the second tabulate area; a section of the inner wall and the central tabulate area.

Closely allied to *C. archiaci* from above locality, is *Eridophyllum verneuilanum* from Columbus, Ohio, the difference in internal structure

between the two being such as might readily be expected of different individuals in the same species. This difference lies in the epithecal projections characteristic of Eridophyllum which are entirely wanting in Craspedophyllum. It seems not unlikely, therefore, that a generic relationship exists between these types. If this be so, Craspedophyllum must be considered as the ancestor. This is further substantiated in the greater specialization of *Eridophyllum verneuilanum* when compared with *Craspedophyllum subcaespitosum.* Thus the Eridophyllum is more specialized in the early expansion to normal size; in the complete inner wall which appears earlier in the life of the individual; and in the additional feature of epithecal projections. If the relationship outlined proves true, it is evident that *Eridophyllum verneuilanum* cannot be genetically related to the Siluric species, *Eridophyllum rugosum* as the latter makes its appearance before the postulated ancestor of *Eridophyllum verneuilanum*, i.e., Craspedophyllum. The characters now relied on for generic distinction being homoeomorphic, these would represent entirely distinct genera, and not as now generally considered, species of one genus. *Eridophyllum rugosum* requires further investigation, which is rendered very difficult as most material is silicified and the delicate internal structure destroyed.

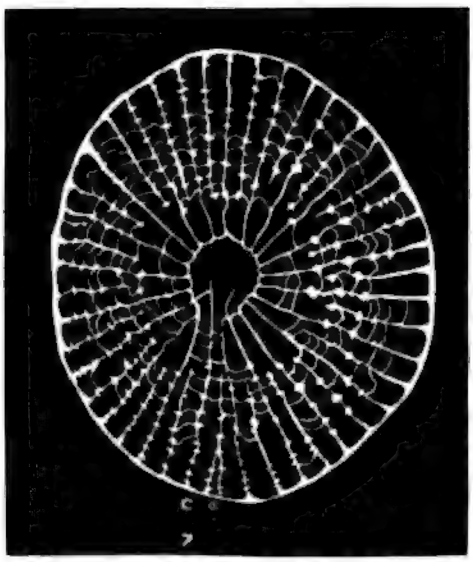


FIG. 7.—Cross-section of mature specimen of *Craspedophyllum archiaci*, showing the incomplete inner wall with the cardinal septum extending into the inner central area.

Other corals with true inner wall.—Hapsiphyllum (Simpson) and Laccophyllum (Simpson) both contain an inner wall; in the former it

is incomplete and in the latter complete. They have, however, scarcely any characteristics in common with the corals above considered. In Laccophyllum the wall is very massive and much thicker than the septa, and in both it is conical in shape, decreasing in diameter toward the tip of the corallite. This feature is reversed in the Craspedophyllum type, as in the latter the inner wall becomes smaller in diameter as the corallite develops. They are good examples of individuals in remote parallel series.

Carinae.—The carinae are not present at the early stage represented in Fig. 1, but the first series is well indicated in Fig. 2. These are formed by bar-like growths extending upward and inward in an arching manner (Fig. 6), and on corresponding sides of the septum. In transverse sections they appear as short cross-bars through the septum (Figs. 2, 5, 7). The mode of growth and the order of appearance of the carinae will be understood from the diagrammatic section, Fig. 8. The difficulty of obtaining a complete longitudinal section of a septum from a specimen is apparent as these seldom if ever develop in a true plane. The diagrammatic section is therefore based upon the development of the carinae at different stages as they are revealed by several longitudinal sections. A general idea is, however, obtained from Fig. 6, where the carinae are revealed in several places. In Fig. 8 it is seen that the tip of the corallite contains no carinae and this would therefore, represent a stage of Fig. 1, or earlier. The first carina appears at the outer wall and grows upward and inward until it finally fades away in the region of the inner wall. As soon as the room is sufficiently large between the first carina and the outer wall, the second carina begins and takes a path similar to the first. A similar direction is taken by each successive carina; all terminating in a like manner, and new ones take their places at the outer wall.

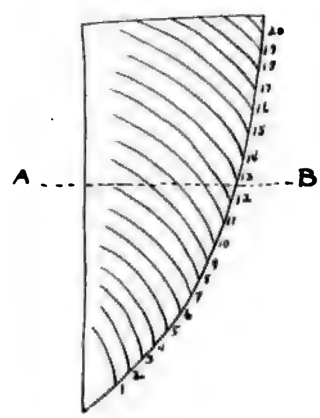


FIG. 8.—A longitudinal diagrammatic section of a septum, with ideal development of the carinæ.

It is evident that if *AB* (Fig. 8) represents a transverse section, there will be four carinae cut and in the order of their appearance these are 9, 10, 11, 12, carina number 9 being the oldest of the four, and carina number 12 the youngest. Hence the oldest carina in any transverse section is the one nearest the center, and they become successively younger toward the outer wall.

Corals with the appearance of an inner wall.—To Strombodes is attributed a rudimentary inner wall by Edwards and Haime (*Brit. Foss. Corals, Intr.*, p. lxx). It does not possess a true inner wall, however, as the coral is composed of superposed lamellae, and the fact that it contains no septa renders the presence of an inner wall impossible. The appearance of an inner wall in Phillipsastrea is the same as that in Acervularia, being formed by pseudo-thecae, and not as the true inner wall. Aulophyllum is considered by Edwards and Haime (*Polyp. Foss. des Terr. Palaeoz.*, p. 413) to contain an inner wall similar to that of Acervularia; hence, it also must be considered as not containing a true inner wall.

In Synaptophyllum (Simp.) and Schoenophyllum (Simp.) the appearance of an inner wall is attributed by their author (*Bull.* 39, *New York State Museum*, Vol. VIII, p. 212), to a thickening of the margin of the inner row of dissepiment through which the septa pass and extend with free inner borders nearly to the center. In Depasophyllum[1] the upturned outer borders of the tabulae, are fused into the lateral area of the short septa forming what appears to be an inner wall which is about two-thirds the diameter of the corallite. The septa are in no way otherwise connected with the inner wall thus formed by the tabulae, and the septa often extend with free inner borders into the central area. The wall is thus formed by the tabulae and not by the inner borders of the septa which is essential in the true inner wall.

The inner wall, as found in the coral containing a true inner wall, which I shall call "bimural corals," is defined as formed originally by the inner borders of the long septa. For this reason the long septa, with the exception of the cardinal septum, cannot extend into the inner central area in "bimural corals," by penetrating the inner wall; herein lies the distinction which differentiates it from the Acervularia type. A longitudinal thin section through the central region

[1] Grabau, *Geol. and Paleon. of the Devonic Formation of N. Michigan* (in press).

of the corallite will always disclose the two sides of the inner wall in the "bimural corals" (Fig. 6), which feature also is wanting in the Acervularia type.

BIBLIOGRAPHY

ACERVULARIA (Schweig)

Edwards and Haimes, *Polyp. Foss. des Terr. Palaeoz.*, p. 419, Pl. 9, Figs. 4, 4*a*, 4*b*, 1851.
——— *Brit. Foss. Corals*, 1850, p. lxx.
Hall, *Report Geol. Surv. Ohio*, 1875, Vol. II, Pt. II, p. 476.
Nicholson, *Geol. Surv. Ohio*, 1875, Vol. II, Pt. II, p. 240.
Schweigger, *Handb. der Naturg.*, p. 418, 1820.

AULOPHYLLUM (E. and H.)

Edwards and Haimes, *Brit. Foss. Corals*, p. lxx, 1850, Pl. 3.
——— *Polyp. Foss. des Terr. Palaeoz.*, p. 413.

CRASPEDOPHYLLUM (Dybowsky)

Billings, "*Diphyphyllum archiaci.*" *Can. Jour.*, Vol. V. p. 260, Fig. 8.
Nicholson, "*Heliophyllum subcaespitosum,*" *Geol. Mag.*, London, 1874, Vol. I, p. 58, Pl. 1, Fig. 9.
Nicholson and Thomson, "Crepidophyllum," *Proc. Roy. Soc. Edinburgh*, Vol. IX, p. 149.
Thomson, "Crepidophyllum," *Ann. Mag. Nat Hist.*, p. 51, 1878.

DIPHYPHYLLUM (Lonsdale)

Lonsdale, *Murch., Vern., Keys., Russia and the Urals*, 1845, Vol. I, pp. 623–24, Pl. *A*, Fig. 4.
Clarke and Ruedemann, *New York State Museum Mem. V*, p. 25.
Edwards and Haimes, *Polyp. Foss. des Terr. Palaeoz.*, p. 446.
Thomson, J., *Quarterly Journal of the Geol. Soc.*, 1887, p. 33.
Hall, "Diplophyllum," *Pal. of New York*, 1852, Vol. II, p. 115.
Lambe, "Can. Paleoz. Corals," *Contributions to Canadian Paleontology*, Vol. IV, Pt. II, p. 157.

ERIDOPHYLLUM (Verneuilanum)

Edwards and Haimes, *Brit. Foss. Corals*, 1850, p. lxxi.
——— *Polyp. Foss. des Terr. Palaeoz.*, p. 424, Pl. 8, Figs. 6, 6*a*.

HAPSIPHYLLUM (Simpson)

Simpson, *Bull.* 39, *New York State Museum*, Vol. VIII, p. 203, Fig. 10.

LACCOPHYLLUM (Simpson)

Simpson, *Bull. 39, New York State Museum*, Vol. VIII, p. 221, Figs. 7, 8, 9.

PHILLIPSASTREA (D'Orbigny)

D'Orbigny, *Note sur des Poypiers fossiles*, 1849, p. 2.
Edwards and Haimes, *Brit. Foss. Corals*, Intr., p. lxx.

SCHOENOPHYLLUM (Simpson)

Simpson, *Bull.* 39, *New York State Museum*, Vol. VIII, p. 214, Figs. 39, 40.

STROMBODES (Schweig)

Edwards and Haimes, *Brit. Foss. Corals*, p. lxx.

SYNAPTOPHYLLUM (Simpson)

Simpson, *Bull.* 39, *New York State Museum*, Vol. VIII, p. 212, Figs. 33, 34, 35, 36, 37.

EDITORIAL

The opinion is gaining some currency in geological circles that the official geological surveys, national and state, are likely to become, at no distant day, little more than economic bureaus administered for their immediate serviceability to industrial enterprises. It is even apprehended that they may drift so far in this direction that they will fall short of being, in the highest, broadest, and truest sense, economic, since this involves the development of the deeper scientific values which are the foundation of the sounder economics.

Running as the mate to this forecast is the complementary prophecy that the evolution of geological science and of its educational economics will be relegated essentially to the universities.

It must be acknowledged that there is some ground in current drift for these twin forecasts. If it were possible to find an absolutely impartial and thoroughly competent jury to pass upon the work of the past decade, its verdict would possibly be that the larger and more far-reaching contributions to the science of geology have come from the universities, and that their relative productiveness in this field has been markedly increasing. It might even be decided that the most valuable contributions to the working methods of the science, especially those of the more searching and refined class, have also come from the universities. At the same time it would doubtless be decided that the economic efficiency of the governmental surveys has been notably increased and the adaptability of their results to immediate commercial demands has been markedly enhanced. Very likely a perfectly impartial judge, surveying critically the appropriate function of the official surveys, on the one hand, and of the universities, on the other, would give his approval to some notable divergence of effort along the lines that have thus been realized in recent practice, if it were controlled by appropriate limitations. At the same time he would doubtless recognize that no small restraint upon excessive tendencies in either direction is quite essential to the permanent success of the surveys, if not also of the

universities. If the surveys become narrowly economic and concern themselves chiefly with conventional descriptions and mappings, interpreted along inherited lines, without the inspiration and regenerative influence of profound investigation, it is not difficult to foresee that in a very short period their products would fall so far below those of the progressive geologists who are engaged in advancing the science that discredit would be brought upon the surveys and their overthrow or reorganization invited. The ultimate good standing of official work is intimately dependent upon a constant revision of basal ideas and a persistent improvement of methods founded upon an ever-increasing command of the fundamental principles that underlie the science, and stimulated by a perpetual search for more complete knowledge. This is as true of the economic phases of the science as of any other. Besides this, it is impossible to foresee accurately what may and what may not come to have economic value. It may be predicted with much confidence that not a few new aspects of the science whose economic relations are as yet wholly unrecognized will prove to be among the most valuable contributions to the broader and deeper economics of the future.

If the universities were supplied with the requisite means, they might be disposed to accept complacently the foreshadowed alternative assigned them. To come into an essential monopoly of the immeasurable riches that lie scarcely concealed beneath the surface of existing geological science might well be regarded by them, from the narrow point of view, as a boon to be welcomed with ardor. To be thus left free to rework the relatively raw results of surveys made for immediate industrial ends, and to bring forth from them by supplementary inquiry their true scientific riches, might, speaking again narrowly, be a source of great seeming advantage to the universities. The universities, however, are not now supplied with adequate means for cultivating this great field. They are gaining these rapidly, and might doubtless attain them at an early day, if so inviting a field is to be thus measurably vacated for them.

But, from the higher point of view, it seems clear that any sharp differentiation of the kind foreshadowed, if it were permitted to go beyond the most moderate and restrained limits, would be injurious to the sum-total of results, and to the larger interests of both univer-

sities and surveys. That it would be little less than fatal to the official surveys, in the long run, is scarcely to be questioned, as they and their results would fall into disrepute unless constantly fed by new science, new methods, and new men broadly and thoroughly equipped. That it would be unwholesome for the universities to be dissevered from industrial work for the common good and to be out of sympathy with official surveys is scarcely less obvious. The higher interests of the surveys and the universities alike will be conserved by a harmonious co-operation in which both shall strive to reach at once scientific and economic results. Differences in the relative stresses and proportions of immediate effort, in the one direction or the other, are obviously appropriate and laudable; but no university can wisely neglect the useful side of the science it cultivates, nor can any official organization, without jeopardy, ignore the profounder scientific aspects of the field it cultivates.

But, above all, intellectual economics should not escape recognition. The intellectual wealth of the nation is its greatest wealth. The contribution which intellectuality has made to the present material prosperity, even if we weigh nothing higher, is perhaps its greatest contribution. Large as are our native resources, they would yield a relatively small return to our people, were it not for that acute mental activity, that signal intellectual power, and that abounding sagacity which so distinctly characterize the present industrial evolution. This intellectuality lies not so much in the mere possession of technical knowledge as of insight, constructive genius, and aggressive mental energy; and these are fostered more effectually perhaps by the influence of independent original research, by the modes of thought and the spirit of investigation, than by any other single agency.

By as much as these intellectual possessions are our greatest assets, by so much would a failure to promote them in the most effective manner be the greatest of economic shortcomings, whether on the part of an official organization or of a university.

T. C. C.

Reviews

Geodetic Operations in the United States 1903–1906. A Report to the Fifteenth General Conference of the International Geodetic Association. By O. H. Tittmann and J. H. Hayford. Washington, 1906. Pp. 45.

While this paper embraces, as indicated, a statement of the principal operations of the Coast and Geodetic Survey for 1903–6, its chief contribution relates to the figure of the earth. The part of special interest to geologists is that which deals with the relation of variations of density in the outer part of the lithosphere to the great surface reliefs. The investigation bearing upon this point was based wholly on the deflections of the vertical, no use being made of determinations of force of gravity. The area treated extends over 18° 51′ in latitude and 50° 7′ in longitude. Astronomic determinations of the deflection of the vertical to the number of 507, all connected by continuous primary triangulation, were used.

It has long been known that the force of gravity on the surface of the earth is not distributed as though the sub-surface material were either homogeneous, gravitatively, or symmetrical. The investigation set forth in this paper, while fully confirming this, goes much beyond any previous inquiry in determining the nature of the inequalities in the distribution of gravity and their correlation with topography. It thus constitutes a very notable advance in this important line of research. The deflections of the vertical that are assignable to variations in the topography, considered by itself alone, were first determined in a very comprehensive way, the effect of the reliefs within a radius of 4126.4 kilometers being computed for each station. The results clearly indicated that the material of the protuberances, viewed largely, has less inherent gravity than that of the basins—a conclusion in accord with the general tenor of previous inquiries in different periods of the world. It remained therefore to determine the distribution of the internal inequalities of density thus disclosed.

The essential feature of the problem was to find out whether the differences of density are so distributed that the continental and oceanic columns balance one another or not, and, if they do, at what depth the equation is established. A series of hypotheses relative to this were adopted as the bases of trial solutions. While these hypotheses, so far as they enter

into the real inquiry, related solely to the distribution of gravity, they have been associated by the authors with ideas of rigidity and isostasy, the purpose of this undoubtedly being to give to the inquiry a definite relation to geophysical problems. While this purpose is eminently laudable, it is not clear to the reviewer that this particular association with questions of rigidity and isostasy is altogether happy, as will be indicated later. These terms will therefore be omitted from the following statement of the hypotheses on which the trial solutions were based, though the term "isostatic compensation" will be retained as a convenient expression of gravitative equilibrium reached by variation in density.

Five trial solutions by the method of the least squares were made on the basis of five hypotheses of the distribution of density, as follows:

Solution A was based on the assumption that there is a complete isostatic compensation at the depth zero beneath the ocean floor; that there exists immediately below every elevation a defect of density fully compensating for the elevation, and that at the very surface of the ocean floor there lies material of the excessive density necessary to compensate for the depression of this floor.

Solution B was made on the assumption that the portions of the continent above the sea-level are excesses of mass, and that the oceans represent deficiencies of mass, and that no isostatic compensation exists; or, in other words, the solution was based upon the supposition that, if isostatic compensation exists, it is uniformly distributed through an indefinite depth.

Solution E was made on the assumption that isostatic compensation is complete and uniformly distributed throughout a depth of 162.2 kilometers.

Solutions H and G were of the same type as E, but based on the assumptions that the depths of compensation are 120.9 and 113.7 kilometers respectively.

The sums of the squares of the residuals of these different solutions were as follows:

Solution A, depth of compensation zero	13,837
Solution B, depth of compensation infinity	65,104
Solution E, depth of compensation 162.2 kilometers	8,174
Solution H, depth of compensation 120.9 kilometers	7,987
Solution G, depth of compensation 113.7 kilometers	7,983

It is to be noted that in Solutions E, H, and G the density compensation is assumed to be *uniformly* distributed to the depths named measured from the varying surface of the lithosphere. Of these solutions, G, having

the smallest sum of the squares of the residuals, is regarded as the closest approximation to the truth.

It thus appears that the inferior densities and greater protuberances of the continental reliefs are such that their joint gravitative effects are balanced by the greater densities and negative protuberances of the oceanic basins at a depth of about 114 kilometers, or 71 miles, if the deficiencies and excesses of density respectively remain uniform to this depth. It was not found possible, however, to determine, from the observations on the deflection of the vertical now available in the United States, whether this or some other was the actual mode of distribution of the compensating densities. The authors recognize, as a possible alternative, a distribution in which the compensating differences of density are greatest at the surface and decline uniformly to a vanishing point, which would be reached at a depth of about 109 miles. The authors speak of the former mode of distribution as more probable than the latter, but whether this is based upon considerations growing out of the reduction of the observations or upon geophysical views is not indicated. From the geological point of view, it seems to the reviewer that a decline in differences of density from the surface to a vanishing point is much more probable than uniform differences ceasing suddenly at a given horizon. It seems, furthermore, that a varying decline from a maximum near the surface to a vanishing point in depth is more probable than either. Especially does it appear probable that a vanishing differentiation below represents the true condition when account is taken of the great depth to which the compensating densities reach as disclosed by this investigation.

A vanishing differentiation of density, rather than a uniform one ceasing abruptly, would seem to be probable under any recognized hypothesis of the origin and mode of formation of the earth that is built upon consistent and plausible grounds. None of the older current hypotheses respecting the mode of formation of the earth, so far as we know, postulates a lateral differentiation of densities at so great a depth as 70 to 100 miles; but if these hypotheses are modified so as to be brought into conformity with these new determinations in the matter of depth, it would seem that, to be consistent with the conditions of the case, they must, in all probability, involve increasing horizontal differentiations from the lowest horizon at which these were developed to the surface, and that these would most probably have a differentially varying value.

The theory of accretion from planetesimals is perhaps the only one which has definitely postulated a horizontal differentiation of densities at horizons of so great depth. It specifically assigns to the continental and

oceanic sectors differences of specific gravity reaching to these and greater depths, and attributes them to differential weathering supposed to have begun at a relatively early stage in the growth of the earth, and to have increased upward at more than a simple ratio until the surface was reached.[1] The effects of the original differentiation by weathering are supposed to have been subsequently modified by vulcanism in such a way that the lighter portions of the differentiated material were brought to or toward the surface in larger percentage than the heavier material, the effect of which was to concentrate the differences of density previously developed toward the surface. The final differentiations of density thus postulated would therefore be greatest at the surface, and would decline downward at a varying rate, whose nature may be roughly indicated by the curve *C–C* in Fig. 1, where it may be compared with the rectangle *AAA* and with the triangle *ABB* which represent the two modes of compensatory distribution referred to above. So far as the reviewer can judge from an inspection of the data furnished by the paper, a distribution of densities such as is represented by the curve *C–C* would satisfy the requirements of the observations as well as either of the others. It would seem, therefore, to be a matter of some felicity that the accretion hypothesis should have assigned, on its own grounds and as the inevitable result of the processes it postulates, a specific differentiation and distribution of densities in fairly close accord with these new determinations based on wholly independent considerations.

FIG. 1

The authors speak of Solution B as being based on the supposition that the earth is rigid, and of Solutions E, G, and H as though they represent isostasy. They say that the investigation "*leads to a definite and positive conclusion as to rigidity versus isostasy.*"[2] They add:

For the United States and adjacent areas, the assumption of extreme rigidity is far from the truth. On the contrary, the assumption that the earth is in the condition called isostasy is a comparatively close approxima-

[1] Chamberlin and Salisbury, *Geology*, Vol. II, pp. 107–11.

[2] P. 10; italics theirs.

tion to the truth. In other words the United States is not maintained in its position above sea-level by the rigidity of the earth, but is, in the main, buoyed up, floated, because it is composed of material of deficient density.[1]

So far as the reviewer can see, that which is really determined does not extend beyond the distribution of density, and all that is added to this is inference or interpretation. It is therefore consistent with the very highest appreciation of the value of the determinations to question the validity of these superimposed interpretations.

The authors are probably entirely correct in assuming that the distribution of specific gravities postulated in Solution B could not be maintained without great rigidity in the deeper portion of the earth. It is equally beyond the probabilities that such a distribution of matter could ever have arisen under any tenable hypothesis of the mode of the earth's formation. But, while the maintenance of this unrealizable condition of things is excluded by the investigation, it is not apparent that it excludes rigidity under more tenable conceptions of the formation of the earth. The exclusion of an extreme and indefensible hypothesis does not logically cover all other hypotheses. It is possible that the authors did not really intend to convey the impression that the conceptions of rigidity held by certain physicists and geologists were incompatible with their determinations, but their language seems to imply this.

So, on the other hand, when the authors say "The United States is not maintained in its position above sea-level by the rigidity of the earth, but is, in the main, buoyed up, floated, because it is composed of material of deficient density," their language carries the impression of a positive affirmation of liquidity or viscousness at the base of the crust in which the differentiated densities reside. Such is the usual conception that goes with the term "isostasy" as it has been used in geological literature. Now, that which is really demonstrated in this important investigation is simply that the compensation of densities becomes approximately complete somewhere between 50 and 150 miles below the surface. The agencies which have produced this differentiation of densities and the physical conditions which now maintain it do not seem to be really touched by the investigation, but to be matters of inference or interpretation based upon other considerations. In the judgment of the reviewer, this differentiation may have arisen and may be now maintained without involving any nearer approach to fluidity than that which is manifested by bodies whose rigidities range from the best granite to the best steel and beyond. Deformations by molecular transfers from crystal to crystal without essentially

[1] P. 10.

affecting the state of rigidity ought now to be regarded as at least a plausible, if not an established, geophysical process, as urged by Van Hise and others in relation to the so-called flowage of crystalline rock, and by Chamberlin and others in relation to the so-called flowage of glaciers. A condition of gravitative balance essentially equivalent to that arising from isostatic flotation may thus be reached in great masses of matter which are at every instant and in all parts affected by a high degree of rigidity. Under this conception the protuberant area of the United States may be supported by a base which is rigid in the truest sense of the term. In this case it could be said to float on its base in no more appropriate sense than the Greenland ice-fields may be said to float on their rock bottom.

There is a specific objection to entertaining the conception of a crust of 70 or 100 miles floating on a mobile substratum. A crust of that thickness, if formed of the firmest granite, would still have but a limited power of accumulating lateral stresses, and hence must yield to such stresses as fast as they reach a moderate magnitude and give rise to practically continuous folding. It is, however, quite certain that most mountain foldings took place in relatively short periods. We seem therefore to be shut up to the alternative of supposing either that the agencies which produced mountain foldings came into play for short periods only and then ceased, or that the body of the earth is capable of accumulating stresses for a long period until, having attained large magnitude, they reach the limits of resistance and deformation ensues in a comparatively short period. The former hypothesis does not seem to the reviewer to have been assigned a competent basis and a working method, while the latter appears to find such a basis in the pervasive rigidity of the outer half of the earth implied by various astronomical and physical data, provided depths of several hundred miles, affected by high rigidities throughout, are assumed to act in strict co-ordination in withstanding deformation during the period of stress accumulation. There are, therefore, serious grounds for hesitating to accept conclusions involving fluidal or viscous mobility beneath a shallow sub-crust, unless the evidence is direct and specific.

If that portion of the paper which relates to rigidity and isostasy be put into the category of inferential and interpretative matter, to which there are at least recognized, if not plausible, alternatives, the positive determinations, standing as they seem to do on a firm basis, may well be regarded as constituting a contribution of the first order of importance.

T. C. C.

To anticipate any misapprehension that might have crept into the foregoing review or that might grow out of it, the manuscript was submitted to the authors of

the paper with an invitation to suggest points of revision or to add a statement to go with it. In response to this, the following comments have been prepared by Mr. Hayford. In the light of these, the review might well be modified at some points, but to avoid disturbing the basis of Mr. Hayford's comments it is left precisely as submitted.—T. C. C.

COMMENT ON THE ABOVE REVIEW BY MR. JOHN F. HAYFORD

The Report reviewed on the preceding pages by Professor Chamberlin, is essentially a preliminary statement. It was necessarily short, being one of many presented by various countries to the International Geodetic Association for publication in its triennial report. Another short preliminary statement in regard to the same investigation is also available in print, in the *Proceedings of the Washington Academy of Sciences.*[1] Both of these statements are subject to defects due to brevity. So, also, must the statement here made be brief and defective. It is hoped that a much more complete statement of the investigation may be published by the Coast and Geodetic Survey within a year from date.

The fair and clear review by Professor Chamberlin is welcomed by the undersigned. A few statements seem to be necessary, in justice to the geodetic investigation under discussion, in order that there may be no misunderstanding.

Professor Chamberlin's distinction between demonstration and interpretation, in connection with this investigation, is correct. The investigation demonstrates that the present distribution of densities follows a certain law. The statement of the meaning of this law in terms of rigidity is interpretation, and this interpretation depends, in part, on considerations outside the scope of the geodetic investigation. It seems to the writer, however, that the interpretation, given in terms of rigidity, is reasonably safe. When the interrelations of the geodetic and geologic evidence are more fully appreciated than at present, it is believed that others will reach the same conclusion.

Before discussing isostasy, it is necessary to get a clear conception of what the word means. It is stated in the review that certain language in the Report "carries the impression of a positive affirmation of liquidity or viscousness at the base of the crust in which the differentiated densities reside. Such is the usual conception that goes with the term 'isostasy,'

[1] John F. Hayford, C.E., "The Geodetic Evidence of Isostasy, with a Consideration of the Depth and Completeness of the Isostatic Compensation and of the Bearing of the Evidence upon Some of the Greater Problems of Geology," *Proc. Wash. Acad. Sci.*, Vol. VIII, pp. 25–40 (May, 1906). The writer will be glad to furnish copies of this paper to interested persons.

as it has been used in geological literature." The language used in the Report was not intended to give the impression stated in the words just quoted. The writer, being aware that the word "isostasy" has been frequently misunderstood and used inaccurately, carefully defined it at considerable length in both his preliminary statements before the Washington Academy and the Geodetic Association. The idea of a crust composed of relatively rigid material, floating upon a liquid or viscous substratum, is not necessarily implied in these definitions. Nor is it necessarily implied in the original definition of isostasy by Dutton.[1] The floating crust represents one possible method of isostatic adjustment. Dutton does not believe in a floating crust, nor does the writer. The geodetic investigation under discussion contains strong evidence, not set forth fully in either preliminary statement because of lack of space, which is against the crust hypothesis. The condition of approximate equilibrium called isostasy may exist in materials in which there are no sudden changes in viscosity.

In his review Professor Chamberlin states that, under the accretion hypothesis, an initial arrangement of densities might be produced such that the condition of approximate equilibrium called isostasy would exist, and that therefore the present existence of isostasy does not necessarily prove anything in regard to the rigidity or lack of rigidity of the earth. The following quotation[2] shows that the writer recognizes that such an initial condition may have existed, but that he also recognizes that, even if it did exist, the present facts still constitute a proof of low rigidity and of isostatic readjustment:

> It is possible that the continents and oceans are in their present positions because light materials accumulated at the outset in the places now occupied by the continents, and heavier material accumulated where the deep oceans now lie. This would constitute an initial isostatic adjustment. But the geologic evidence is overwhelming that within the interval covered by the geologic record many thousands of feet of thickness have been eroded from some parts of the earth, and have been transported to and deposited upon other parts. If isostatic readjustment had not also been in progress during this interval, it would be impossible for the isostatic compensation to be so nearly complete as it is at present.

The writer believes the degree of completeness of the isostatic adjustment to be a measure of the degree of effective rigidity, under forces con-

[1] C. E. Dutton, "On Some of the Greater Problems of Physical Geology," *Bulletin of the Philosophical Society of Washington*, Vol. XI, p. 53.

[2] Hayford, *The Geodetic Evidence of Isostasy*, p. 35.

tinuously applied for a long time, of the material composing the outer part of the earth. A flowage of rocks, of the character referred to in Professor Chamberlin's review, may be one of the ways in which the material yields to forces continuously applied for a long time, even though those forces are not sufficiently great to produce motion if applied for a short time only.

Professor Chamberlin has, in the curve *C–C*, furnished a statement of the manner of distribution of the isostatic compensation with respect to depth corresponding to the accretion hypothesis. Since writing this review, Professor Chamberlin has been assured that a sub-solution upon that basis will be added to the geodetic investigation before the final publication is made.

JOHN F. HAYFORD
Inspector of Geodetic Work
Chief of Computing Division, Coast and Geodetic Survey

The Geology of South Africa. By F. H. HATCH and G. S. CORSTROPHINE. London and New York: The Macmillan Co., 1905. Pp. 348, 2 maps, 89 figures.

The authors have attempted in this work to put within the limits of a small volume the essentials of the geology of South Africa. Their long experience in South African geology, both in the Transvaal and Cape Colony, has fitted them well for their task. The literature of South African geology is especially burdened with a great mass of semi-scientific writings which deal with isolated areas, without any attempt at correlation with neighboring regions, and only recently by the work of the Cape Colony and Transvaal surveys, has geological work been carried to a stage that would warrant the treatment of South Africa as a unit. The book contains some details that were hardly intended for the student so far away as America, and, on the other hand, many general points of vital interest are passed over all too briefly. This is especially true of the physical history and dynamical problems of the region. Nevertheless, the volume is a valuable and welcome summary of the geology of this distant land.

The "pre-Karroo" (pre-Permo-Carboniferous) rocks are treated in two sections: Section I describes those of south Cape Colony; Section II those of the Transvaal and neighboring regions. At the base, in both regions, is a series of micaceous slates and quartzites with occasional conglomerates and crystalline limestones, into which were intruded granite

masses, causing considerable metamorphism, and resulting in a great variety of schists. This series is classed as Archean.

The great group of rocks resting unconformably on the Archean, and below the Cape System (the upper part of the pre-Karroo group), has not yet been correlated with the formations of other countries. They consist of slates, quartzites, grits, conglomerates, and dolomites. In the Transvaal the group has a thickness of 35,000–40,000 feet, and includes three unconformable systems; the lower one of which, the Witwatersrand, consists of twelve formations and has a thickness of 20,000 feet. The conglomerate beds of the Witwatersrand contain valuable gold deposits, having an output, in 1904, of about $70,000,000. The second system of the group is largely volcanic; the third is made up of clastics and dolomites.

The Cape system consists in its best development (south Cape Colony) of three conformable series of slates, quartzites, shales, and sandstones. The middle series, the Bokkeveld, contains the oldest recognizable fossils found in South Africa. They are of Devonian age.

The "Karroo system" is a conformable series beginning with Permo-Carboniferous strata, and extending to the end of the Triassic. The system has a thickness of about 20,000 feet, and is composed of sandstones, shales, and conglomerates. It outcrops in an elliptical northeast-to-southwest area covering three-fourths of South Africa. In south Cape Colony it rests conformably upon the Cape system, but elsewhere it is unconformable on older rocks. At the base of the system is the Dwyka glacial conglomerate of Permian age.

The "Coastal system" (Cretaceous) consists of two series occurring in different regions; one is of Lower, the other of Upper Cretaceous age.

Post-Cretaceous beds are represented by superficial deposits, usually cemented, which probably range from Tertiary to quite recent, but in the absence of fossils they are not classified.

The igneous rocks of known age are discussed along with the sedimentary series and chap. i of Part IV treats some volcanic rocks of doubtful stratigraphical position.

Chap. ii of Part IV is devoted to the occurrence and origin of the diamond bearing deposits.

In Part V the authors discuss the correlations of the strata of the various regions of South Africa and their position in the geological column. The correlation tables here and in other parts of the book are especially valuable.

The chief subdivisions are here reproduced.

CORRELATION TABLE OF SOUTH AFRICAN STRATA

European Equivalents	Southern Cape Colony	Northern Cape Colony	Natal	Transvaal
	Superficial Deposits	Superficial Deposits	Superficial Deposits	Superficial Deposits
Cretaceous..	Coastal System { Umtamvuna Series, Uitenhage Series }		Coastal System { Umtam-vuna Series }	
Rhaetic .... Permo-Carboniferous.	Karroo System { Stormberg Series, Beaufort Series, Ecca Series }	Karroo System { Ecca Series }	Karroo System { Stormberg Series, Beaufort Series, Ecca Series }	Karroo System { Ecca Series }
Devonian ..	Cape System	Cape System	Cape System	Waterberg System
	Congo System	Griqualand System		Potchefstroom System
	Ibiquas ?	Amygdaloids of the Vaal River		Ventersdorp System
				Witwatersrand System
Archean	Malmesburg System	Namaqualand System	Swaziland System	Swaziland System

J. E. C.

New York State Museum, Bulletin 99. Geologic Map of the Buffalo Quadrangle. By D. D. LUTHER, 1906. Pp. 29 and geologic map.

This bulletin is the latest one, prepared under the direction of Dr. John M. Clarke and published by the New York State Museum, devoted to the mapping and description of the geologic formations of a quadrangle. As is customary with this series of bulletins, it contains a map on which the areal distribution of the various formations is shown, accompanied by a text giving an account of their occurrence and characters together with lists of their common and diagnostic fossils. As stated by Dr. Clarke, "students of geology in Buffalo will find the map and its accompanying text a detailed guide to the rock sections of the region and to the scattered and often obscure outcrops of the formations, and, since this is the second largest city in the state, the bulletin will be of special service to a large number of people.

The strata composing the surface rocks of this quadrangle have an aggregate thickness of over 800 feet and are of Devonian age, with the

exception of the Salina beds and Cobleskill waterlime which are in the Upper Silurian. From an economic standpoint the Bertie waterlime at the top of the Salina beds is the most important division of the Silurian rocks, since it is extensively quarried in North Buffalo and Williamsville for the production of natural cement. Paleontologically, the Bertie waterlime is characterized by an "abundant and peculiar crustacean fauna" of lobster-like forms belonging in the extinct orders of Eurypterida and Phyllocarida. The highest bed of the Upper Silurian in the Buffalo region, in somewhat earlier papers, had been referred either to the Onondaga or Manlius limestones, but recently has been correctly correlated by Hartnagel with the Cobleskill limestone (formerly Coralline) of eastern New York. The Rondout waterlime and Manlius limestone of the Upper Silurian and the Helderbergian limestones of the Paleo-Devonian do not reach western New York, so that the oldest Devonian rocks rest unconformably by erosion upon the Cobleskill waterlime. The quartz sand filling the fissures in the Cobleskill waterlime, which infrequently extend down into the Bertie, is considered Oriskany sediment and, consequently, the oldest Devonian deposit. The oldest well-represented Devonian formation is the Onondaga limestone, with a thickness of about 160 feet, which is quarried extensively for building-stone and the production of quicklime. This limestone contains a considerable amount of carbonaceous matter, nodular layers of chert, and large numbers of fossils.

The Onondaga limestone is followed by the Marcellus beds which are divided into the Marcellus black shale, representing the typical shales occurring at Marcellus, the Stafford limestone, and the Cardiff shale. The Hamilton beds are well shown at various localities on the southern part of the quadrangle and are divided in ascending order into the Skaneateles and Ludlowville shales, Tichenor limestone, and Moscow shale. Fossils are abundant in all of these divisions, with the exception of the lowest one—the Skaneateles shale. The Hamilton beds are succeeded by the Genesee beds of which the typical Genesee black shale is practically absent. The Genundewah limestone, an irregular concretionary stratum, 1 to 2 feet thick, and the West River shale, about 12 feet in thickness, are well shown. The limestone in many places is composed largely of the shells of the minute Pteropod, *Styliolina fissurella*, and, on that account, has also been called the Styliola limestone. The Portage beds are the youngest ones described and on this quadrangle the subdivisions of the Middlesex black shale, the Cashaqua shale, and the Rhinestreet black shale occur. The two black shales of the Portage contain comparatively few fossils; but they are fairly common in the Cashaqua shale and its interbedded calcareous, concretionary layers.

C. S. P.

PERIDOTITES AND CORUNDUM

[AUTHOR'S ABSTRACT]

Corundum and the Basic Magnesian Rocks of Western North Carolina. By J. VOLNEY LEWIS. *Bulletin*, North Carolina Geological Survey, No. 11, 1896.

Corundum and the Peridotites of Western North Carolina. By JOSEPH HYDE PRATT and JOSEPH VOLNEY LEWIS. *Reports*, North Carolina Geological Survey, Vol. I, 1906.

Corundum and its Occurrence and Distribution in the United States. By JOSEPH HYDE PRATT. *Bulletin*, U. S. Geological Survey No. 269, 1906.

Although a decade elapsed between the appearance of the first and the last two of the above publications they are so intimately connected that they should be reviewed together.

The first is a record of the distribution and the modes of occurrence of the peridotites and the associated corundum deposits of western North Carolina, with briefer descriptions of similar occurrences throughout the eastern crystalline belt of the continent.

The second is an elaboration and revision of the first, particularly as regards the petrography of the peridotites and the mineralogy of corundum and the associated minerals. It differs essentially from this, however, in that it takes up quite fully the theoretical questions of origin and relationships of the various rocks and minerals concerned.

The third publication listed above, although bearing the name of but one of the authors, is essentially a rearrangement of the subject-matter of the other two, with the omission of most of the petrography and a slight enlargement upon important localities outside of North Carolina. It is, in the main, a reprint, both in text and illustrations, although this fact is nowhere indicated. A footnote on p. 28 merely refers to the North Carolina report, without naming the authors or intimating that the text is the same. Joint authorship for four pages of text is acknowledged, however, in a footnote on p. 62, and the reader is left to infer that the remainder is the work of the author whose name appears on the title-page.

This review is therefore chiefly concerned with the second, *Corundum and the Peridotites of Western North Carolina*, which constitutes the first volume of a new series of reports of the North Carolina Geological Survey. It is a volume of 464 pages, is illustrated by 45 plates and 35 figures in the

text, and is in many respects a work of much broader scope than the title indicates.

As stated in the preface, the petrography was chiefly the work of Lewis, and the mineralogy was in charge of Pratt. Other portions of the work are the result of collaboration, and there was a constant interchange of all manuscript for criticism and revision. The individual work of the authors was done, for the most part, at different times and places, each working independently. Notwithstanding this fact, each was led to essentially the same conclusions in regard to the origin and relations of both the peridotites and corundum. Concerning corundum in the basic magnesian rocks, very similar, and in some respects supplementary, hypotheses were deduced by the one from a study of the mines in the peridotites and by the other from the petrology of the corundum-bearing amphibolites and anorthosites. (Cf. pp. 144 and 344.)

A brief sketch of the geology of the state is given in chapter i, with a somewhat fuller account of the belt of gneisses, granites, and schists constituting the rugged mountainous section in which the peridotites and the corundum deposits occur.

Chapter ii deals with the peridotites and the associated basic magnesian rocks. These include four varieties of peridotite, four pyroxenites, four gabbroic rocks, an amphibolite, and three diorites. These are chiefly well-known types. An exception is the pyroxenite composed of the orthorhombic pyroxene, enstatite. This rock occurs somewhat commonly throughout the region, and forms many masses of considerable extent. The name *enstatolite* is proposed for this type, in conformity with the terms "bronzitite" and "hypersthenite." All of these rocks are shown to be a part of the great series of basic magnesian rocks which extends throughout the whole length of the eastern crystalline belt from central Alabama to the Maritime Provinces of Quebec, and again reappears in Newfoundland. Together they constitute a petrologic unit of remarkable persistence and uniformity of characters and association.

Maps show the distribution and relations of these rocks to the crystallines in eastern North America and in western North Carolina, besides several detailed maps of portions of the belt of particular interest. The contoured geological map of western North Carolina (Plate II) is the largest and most detailed yet published of this region. The scale is eight miles to the inch and the base is printed in three colors. On this the pre-Cambrian gneisses and schists and the Cambrian (?) metamorphic sediments are represented by tints, while the peridotite dikes and localities of corundum, chromite, and asbestos are shown in bright red.

Following the descriptions of these rocks throughout the Appalachian region, the distribution and petrographic characters are given in detail for western North Carolina. Sixty photomicrographs illustrate the mineralogic and structural varieties and modes of alteration of the rocks described, and their chemical relations are shown by Hobbs-Brögger diagrams.

Two classes of secondary rocks are described: namely, (1) the mechanically derived schists, gneisses, and gabbrodiorites, and (2) a series of hydrous alteration products, chiefly steatite, chloritite (chlorite-rock), and serpentine.

The vast majority of occurrences, while more or less altered, are essentially fresh primary rocks. This is especially true of the pure olivine-rock, dunite, which is the most common type. Steatite and chloritite are pretty widely found, but serpentine is practically confined to a region within fifteen miles of the French Broad River. Even here remnants of unaltered peridotite are abundant.

The various modes of alteration and decomposition are described in chapter iv. Five distinct processes are recognized, and are designated, except the first, by the prevailing product; namely, (1) weathering, (2) serpentinization, (3) steatitization, (4) chloritization, (5) amphibolization. All of these processes occur more or less together over wide areas, but one or another usually greatly predominates. Hence various areas are characterized by ocherous weathering products or by the abundance of one of the minerals, serpentine, talc, chlorite, and amphibole, with smaller proportions of the others.

The long-vexed question of the origin of the peridotites is discussed in chapter v. A historical sketch shows the kaleidoscopic variety of opinions and hypotheses that have been advanced to account for these rocks since 1875, the date of Professor Kerr's first report on this region. By various authors they have been regarded as unaltered sediments, metamorphic sediments, chemical deposits, metasomatized limestones and schists, and as igneous intrusions. Opinions have been divided chiefly, however, into two groups, corresponding closely to the old Neptunian and Plutonic schools of geology. The strong modern tendency toward the igneous theory of origin is clearly shown, and the correctness of this view is abundantly substantiated by this report. The data presented on this point are grouped under five heads, as follows: (1) mineralogic characters, (2) microscopic characters, (3) gross structures, (4) modes of occurrence, (5) relations to the gneisses and schists.

In the discussion of the general petrology of the basic magnesian rocks, the genetic unity of the series throughout the eastern crystalline belt is

strongly emphasized. It is noteworthy that a closely similar association of rock types is found in almost every peridotite locality, although some one usually preponderates in every case. Thus peridotites, particularly dunite, prevail in North Carolina and Quebec, pyroxenites in Pennsylvania, while gabbros are abundant in Delaware and parts of Maryland. The types represented in the various regions, however, are almost identical, and the petrology is closely similar, except in the relative abundance of the various types and in mode and degree of alteration.

Two generations of corundum are recognized. The greater part, including all deposits of commercial value, belongs to the first generation and represents the excess of alumina in the original magma. Another part, occurring in microscopic grains, is an excess of alumina arising from the corrosion of anorthite crystals by the still molten magma. This process has produced sheaths of minerals which form the *corrosion mantles*, so greatly developed in some localities, and in other cases entirely replacing the anorthite, or the corroding magma, as the case may be, by nestlike aggregates of intermediate silicates.

In discussing the age of the peridotites (pp. 152–59), it is recalled that until recently it has been the custom of geologists to refer the whole of the Appalachian crystalline belt to the Archaean, or at least to pre-Cambrian. Recent work in several regions makes it impossible longer to accept these old correlations without other than merely lithologic evidence. Tables are given showing possible correlations of the crystallines in areas recently investigated, from North Carolina to Massachusetts and the Green Mountains, and summaries are given of the various conclusions as to age arrived at by geologists in different parts of the field. The conclusions of the authors of this report may be briefly stated as follows: The intrusion of the peridotites was probably contemporaneous, or practically so, for the whole region under consideration, from Alabama to Newfoundland. These rocks now form a belt of remarkable unity through a region of great orogenic disturbance and intense metamorphism. These facts, together with the geologic relations that have been deciphered in some northern portions of the belt, suggest the hypothesis that the chief period of intrusion may be correlated with the folding movements of closing Ordovician. The peridotite belt doubtless marks the axis of most intense disturbance. The later orogenic movements, at the close of the Carboniferous, produced the widespread lamination of these rocks, and probably gave occasion for additional minor intrusions. Much painstaking work yet remains to be done, however, in many parts of the field, before any hypothesis concerning the age of the peridotites can be satisfactorily established.

Chapter v closes with a discussion of the secondary rocks. The authors undertake to trace back to their original types the various laminated and hydrated derivatives. The question arises whether the amphibolites, diorites, hornblende-schists, and hornblende-gneisses, may not themselves have been derived from corresponding pyroxenic types, such as occur in the Maryland and Delaware gabbro areas. The fact that undoubted gabbrodiorites do occur in portions of the belt in North Carolina makes it quite probable that many, if not all, of these amphiboliferous types have had a like origin.

Chapter vi deals with the mineralogy and technology of corundum, including its crystallography, its physical and chemical properties, its applications in the arts, and an outline of the process of manufacture of the several types of corundum and emery wheels on the market.

Chapter vii, on modes of occurrence, shows corundum to be a constituent of a remarkable number and variety of rocks, including nineteen igneous types, nine metamorphic, and one unaltered sedimentary. These corundum-bearing rocks are distributed as follows:

CORUNDUM-BEARING IGNEOUS ROCKS

North Carolina	*Other American Localities*	*Elsewhere*
Peridotite	Granite	Kyschtymite
Pyroxenite	Syenite	Diorite
Amphibolite	Nephelite-syenite	Tonalite
Anorthosite	Plumasite	Gabbro
Pegmatite	Norite	Trachyte
	Andesite	Quartz-porphyry
	Monchiquite	Basalt

CORUNDUM-BEARING METAMORPHIC ROCKS

Serpentine	Crystalline limestone	Corundum-schist
Gneiss		Corundum-porphyroid
Mica-schist		Graphite
Quartz-schist		Igneous contacts
Amphibole-schist		Inclusions
Chlorite-schist		

OTHER CORUNDUM-BEARING ROCKS

Alluvial gravels
Undetermined (emery)

The American occurrences, particularly those of North Carolina, are described in detail and compared with similar deposits, when known, in other parts of the world. Those of chief commercial importance in North Carolina are in peridotites, and to a less extent in amphibolites and pyroxenites. The gravel deposits are of interest on account of the corundum gems (rubies) and the garnet gems (rhodolite) that occur in some of them.

In peridotites corundum occurs chiefly (1) in peripheral or border

"veins" which skirt along the borders of many of the massive outcrops, and (2) in interior "veins," extending from the borders toward the center of the peridotite mass. The mode is similar in the pyroxenites and in certain amphibolites. In other amphibolites, the corundum is irregularly disseminated in grains, plates, and nodular aggregates throughout large masses of the rock. Corundiferous pegmatite forms small dikes accompanying and penetrating both peridotites and amphibolites in some localities. The corundum-bearing serpentines, amphibolites, and chlorite-schists are simply derivatives of the foregoing types, with more or less dynamic and chemical alteration and rearrangement. Corundum-bearing gneisses and mica schists, which sometimes pass into quartz-schists, have no relation with the peridotites, although occurring in the same region and sometimes near the outcrops of these rocks. The chief localities of corundiferous peridotites, gneisses, and schists are in Clay, Macon, and Jackson Counties, North Carolina, near the southwestern corner of the state. Scattering occurrences in amphibolites and gneisses are also found east of the mountains, particularly in Iredell County.

The distribution of corundum is considered in chapter viii. First the Appalachian localities are described, including Alabama, Georgia, South Carolina, North Carolina, Virginia, Pennsylvania, New Jersey, New York, Connecticut, and Massachusetts. Occurrences in Montana, Colorado, and California are also described, as well as the corundum and emery deposits of Canada, India, Turkey, and the Grecian islands. North Carolina localities are described in detail, by counties.

The alterations of corundum and the minerals associated with it are described in chapter ix. The list of associated minerals from North Carolina localities includes 62 species, each of which is described, with its mode of occurrence and its relations to the corundum. Chemical analyses and crystallographic characters of many are also given. From other American and foreign localities the number of associated minerals is increased to seventy-four.

The origin of corundum is considered in chapter x. The discussion is prefaced by an account of the artificial production of the mineral and a summary of the various hypotheses that have been advanced during the last twenty-five years. From a consideration of field relations and the later experiments with silicate magmas, the conclusion is reached that the corundum of the peridotites was held in solution in the magma when it was injected into the gneisses, and that it crystallized out among the first minerals formed, as the mass began to solidify. Corundum in quart-schists and gneisses, on the other hand, is the result of metamorphism of

sandstones and shales rich in alumina, which was probably in the form of bauxite.

Methods of prospecting, mining, and milling are described in chapter xi. It is prefaced by a historical sketch of corundum in the East and an account of discoveries and mining in the United States and Canada.

Chapter xii deals with the various other economic minerals of the peridotite belt—chromite, asbestos, genthite, serpentine, and limonite. Chromite in promising quantities has been found at a number of localities in North Carolina, particularly in Yancey and Jackson Counties. Asbestos (chrysotile) of good quality frequently occurs, but no mining has yet developed in North Carolina. The well-known Canadian deposits, however, are in the northward extension of this belt. The nickel ores (genthite and related silicates) occur widely, and are unquestionably derived from the decomposing peridotites, in the joints of which they are found. Serpentine in large bodies is a direct alteration product of the peridotites in North Carolina, but its occurrence is extremely limited, as compared with the abundance of the latter. Residual limonite beds have sometimes been formed from decomposing peridotites, and these have been utilized as iron ores in some portions of the belt in New York and Pennsylvania.

An appendix of twenty pages consists of a bibliography of American peridotites, corundum, and associated minerals. Copious references to both American and foreign literature are also given in footnotes throughout the report.

J. Volney Lewis

Rutgers College
New Brunswick, N. J.

Lower Paleozoic Formations in New Mexico. By C. H. Gordon and L. C. Graton. (*American Journal of Science*, Vol. XXI, pp. 390–95, 1906.)

In *Science* for April 13, 1906, announcement was made of the discovery in Sierra and Grant counties, New Mexico, of formations belonging to the Cambrian, Ordovician, Silurian, and Devonian series. A more extended account of these formations by C. H. Gordon and L. C. Graton of the U. S. Geological Survey appeared in the *American Journal of Science* for May, 1906. A full account of the investigations upon which these announcements are based will appear in a forthcoming report of the U. S. Geological Survey, on the mining districts of New Mexico.

The Cambrian rocks consist of quartzites, sandstones, and shales, with occasional beds of limestone. They range in thickness from 50

feet, in the Caballos Mountains, to about 1,100 feet in the vicinity of Silver City. To these beds in the forthcoming report the name "Shandon quartzite" is applied. They contain Upper Cambrian fossils.

Resting with apparent conformity upon the Cambrian is a series of limestones 900 to 1,200 feet thick. The greater part of these limestones contain a fauna allied to that of the Richmond division of the Upper Ordovician. In some localities a Silurian fauna appears, but no stratigraphic break between these beds and the Ordovician has been recognized, and the indications are that the Silurian beds do not exceed 100 feet in thickness. The data at hand are insufficient to warrant the separation of these strata, and the name "Mimbres" is given to the whole limestone formation.

Resting upon the Mimbres limestones are shales varying in thickness from less than 200 feet in Sierra County to 500 or more in Grant County. The abundant fauna of the lower half of the formation is Upper Devonian. It is of peculiar interest, as it is the same which was discovered years ago in the Ouray limestone in southwestern Colorado by Endlich. It is characterized by *Camerotoechia endlichi* Meek, nót heretofore recognized outside of the San Juan Mountains. For this shale formation the name "Percha" has been adopted.

Lower Carboniferous strata have long been known about Lake Valley, Sierra County. They have not been found at other localities, notably at Hillsboro, Kingston, Cooks, and in the Silver City district. The name "Lake Valley limestones," formerly applied to these beds, has been adopted by the U. S. Geological Survey.

The Post-Tertiary stratified deposits of gravels and sands have great development in the Rio Grande Valley, where their thickness is sometimes 1,500 to 2,000 feet. They occupy old valleys, and the materials are of local origin. The constituents, which are coarse and angular along the borders of the containing depressions, become finer toward the axes of the valleys; and where the valleys are wide, as in the case of the Rio Grande, the axial portions consist principally of sands and incoherent sandstones. In western Sierra County the coarse gravels are in places cemented into a firm conglomerate comparable to that to which the name Gila Conglomerate is given in Arizona. Extensive exposures of the gravels occur along the Palomas River, and the name "Palomas" has been adopted for the formation.

[AUTHORS' ABSTRACT]

THE
JOURNAL OF GEOLOGY

FEBRUARY-MARCH 1907

THE DEVONIAN SECTION OF ITHACA, N. Y.[1] PART II

THE DISCRIMINATION OF THE NUNDA-CHEMUNG BOUNDARY

HENRY SHALER WILLIAMS
Ithaca, N. Y.

[*Concluded from page 598*]

THE CHEMUNG GROUP OF HALL

The name Chemung group was originally proposed by James Hall in the *Third Annual Report* of the New York State Geological Survey (p. 324), published as "Assembly Document No. 275" in 1839. The formation was described and lithologically distinguished from the rocks of the immediately underlying formation by the following characteristics:

The tops of the hills and high grounds in the towns of Erie, Veteran, and Catlin, display a group of rocks and fossils very distinct from those last described. The essential difference is the lithological characters of the sandstone of this group in the absence of argillaceous matter in most of the layers, these being merely a pure siliceous rock, harsh to the touch, and generally of a porous texture; while still a large proportion of the mass consists of compact shales and argillaceous sandstones of a softer texture than those below. The surface of the sandstones is rough, while those below are smooth and glossy, and being never rippled, prove that the rocks were deposited in a quiet sea. (P. 322.)

This definition gives a fair idea of the most conspicuous differences separating the higher from the lower rocks of these sections,

[1] Published by permission of the Director of the United States Geological Survey. Concluded from p. 598 of Vol. XIV, No. 7 (1906).

though it would be difficult to draw a sharp line at the horizon where the change takes place.

The shales of the Nunda and Chemung are similar, but the sandstones of the Nunda are smooth surfaced, often ripple marked, thin and tough in texture; while they are soft, rough surfaced, breaking up with vertical rather than splintery fracture ("blocky" as I have called them), in the Chemung and are often of a lighter color.

In Hall's original definition of the formation certain fossils are mentioned as charactersitic: "The principal ones are a species of *Delthyris* the shell on each side extending into a wing (*D. alata*?) a *Leptaena*, *Orthis*, and a species of *Avicula* or *Pterinea*," etc., but we find a fuller list given in the final report published in 1844. Still more important than this citation of fossils for the purpose of identifying the typical characteristics of the formation is the following statement:

> Between Elmira and Chemung they are seen at numerous points, but nowhere in the county [Chemung] so well as at the Chemung upper Narrows, about eleven miles below Elmira. Here the excavation for the road along the margin of the river has exposed more than 100 feet of rocks, containing abundance of the characteristic fossils, and in their greatest beauty and perfection. (P. 323.)

This quotation indicates where may be found the typical representation of the fauna and, since in later papers the author [James Hall] lessened his belief in the separateness of the faunas of the Ithaca and Chemung, this standard section is important as it enables us now to scrutinize it more closely than Hall did and to discover the paleontologic marks by which it may be distinguished from the fauna underlying it.

Adopting therefore this section at the upper Chemung Narrows as containing the typical Chemung fauna, as recognized at the time of the original recognition and naming of the Chemung group by James Hall, we may select from the fossils named as characteristic of the Chemung group in the final report (1843) those which are known to belong to the section of rocks exposed at Chemung Narrows (*Geol. of Fourth Dist., N. Y.*, pp. 262 ff.).

The species originally mentioned by Hall as coming from the rocks at Chemung and Cayuta Creek[1] (the latter has been found by

[1] Ch.=Chemung; Cy.=Cayuta Creek.

later investigations to represent the same portion of the section as that seen at the cliff at the Narrows above Chemung) are the following, viz.:

Calymene nupera (Fig. 116, p. 262, Ch.) = Phacops nupera.

Avicula pectenformis (Fig. 117, 1, 2, p. 262, Ch., Cy.) = Pterinea chemungensis (Con.).

Avicula spinigera (Fig. 117, 4, p. 262, Ch.) = Leptodesma spiningerum.

Strophomena bifurcata (Fig. 120–2, Ch.) = Orthothetes chemungensis.

Strophomena arctostriata (Fig. 120, 3, Ch.) = Orthothetes chemungensis.

Strophemena interstrialis (Fig. 120, 5, Ch.) = Dovillina mucronata (Con.).

Orthis carinata (Fig. 121, 1, Ch.) = Dalmanella carinata.

Orthis interlineata (Fig. 121, 3, 4, Ch., Cy.) = Dalmanella tioga (Hall).

Delthyris mesastrialis (Fig. 122, 1, 1*a*, Cy.) = Spirifer mesistrialis.

Delthyris disjuncta? H. (Fig. 122, 3, Ch.) = Spirifer disjunctus Sowerby.

Delthyris cuspidata H. (Fig. 123, 1, Ch., Cy.) = Sp. disjunctus Sow.

Delthyris acanthota H. (Fig. 123, 2, 2*a*, Ch., Cy.) = Sp. disjunctus Sow.

Delthyris acuminata H. (Fig. 123, 5, 5*a*, Ch., Cy.) = Delthyris mesicostalis.

Atrypa dumosa (Fig. 124, 1, 1*a*, Ch., Cy.) = Atrypa spinosa (Hall).

Atrypa tribulis (Fig. 124, 3, Ch.) = Atrypa reticularis (Lin).

Cyathophyllum p. (Fig. 273, Ch.) = ?

Conrad[1] in 1842 described several species, the locality of which is sufficiently well certified to refer them to this fauna. The species are (all from Chemung Narrows):

Avicula spinigera (p. 237, Pl. 12, Fig. 3) = Leptodesma spinigerum (Con.).

Avicula protexa (p. 238, Pl. 12, Fig. 6) = Leptodesma protextum (Con.).

Avicula multilineata (p. 241, Pl. 13, Fig. 1) = Avicula multilineata (Con.).

Avicula chemungensis (p. 243) = Pterinea Chemungensis (Con.).

Cypricardites carinifera (p. 245, Pl. 13, Fig. 14) = Goniophora chemungensis.

Inoceramus chemungensis (p. 246, Pl. 13, Fig. 9) = Mytilarca chemungensis (Con.).

Nuculites chemungensis (p. 247, Pl. 13, Fig. 13) = Schizodus chemungensis (Con.).

Strophomena lachrymosa (p. 256, Pl. 14, Fig. 9) = Productella lachrymosa (Con.).

Strophomena lima (p. 256) P. lachrymosa var. lima (Con.).

Strophomena mucronata (p. 257, Pl. 14, Fig. 10) = Douvillina mucronata (Con.).

Strophomena chemungensis (p. 257, Pl. 14, Fig. 12) = Orthothetes chemungensis.

[1] "Observations on the Silurian and Devonian systems of the United States with Descriptions of New Organic Remains," *Jour. Acad. Nat. Sci.*, VIII (Jan. 18, 1842), pp. 228, etc.

Strophomena delthyris (p. 258, Pl. 14, Fig. 19) = (?) Leptostrophia perplana.
Delthyris chemungensis (p. 263) = Spirifer disjunctus.
Atrypa chemungensis (p. 265) = Atrypa reticularis.

In the Final Reports on Paleontology,[1] a large number of species were added to these lists, but for the purpose of determining the typical Chemung fauna and settling its lower boundary these species should furnish conclusive evidence. Those of the list which are restricted in range in this original section may fairly be regarded as diagnostic of the Chemung formation at its typical outcrop.

The two lists contain the following twenty species:

1. Phacops nupera (Hall).
2. Pterinea chemungensis (Hall).
3. Leptodesma spinigerum (Conrad).
4. L. protextum (Conrad).
5. Avicula multilineata (Conrad).
6. Goniophora chemungensis (Conrad)
7. Mytilarca chemungensis (Conrad).
8. Schizodus chemungensis (Conrad).
9. Orthothetes chemungensis (Hall).
10. Productella lachrymosa (Hall).
11. P. lachrymosa var. lima (Hall).
12. Stropheodonta (Douvillina) muconata (Vanuxem).
13. Leptostrophia (? perplana) delthyris (Conrad).
14. Dalmanella carinata (Hall).
15. Dalmanella tioga (Hall).
16. Spirifer disjunctus (Sowerby).
17. Spirifer mesistrialis (Hall).
18. Delthyris mesicostalis (Hall).
19. Atrypa spinosa (Hall).
20. Atrypa reticularis (Linn).

Of these species No. 1, *Phacops nupera*, is a variety of the common species *P. rana*, if not identical; but it was obtained from a loose block, as we are told in *Paleontology*, Vol. VII, p. 27, so that it is not certainly a part of the original Chemung fauna.

No. 5, *Avicula multilineata*, is not referred to in later literature, and for correlation purposes it is too rare to serve as a diagnostic species.

No. 8, *Schizodus chemungensis*, is reported as from "near Ithaca and Cortland,"[2] and as the rocks of these localities are now known to lie at a horizon lower than the rocks of Chemung Narrows, the species ceases to be diagnostic of the latter formation.

No. 9, *Orthothetes chemungensis*, as a species has a considerable range: it is quite variable in its Chemung expression, so that the name without restriction will not constitute it a diagnostic species of the Chemung.

[1] *Paleontology of New York*, Vols. IV, V, VI, VII, and VIII.

[2] *Paleontology of New York*, Vol. II, p. 454.

No. 13, called *Strophomena delthyris* by Conrad, is quite distinct from the form described by the same name under the name *Strophomena perplana* to which it has been referred by Hall. If it be a variety of *Str. perplana Conrad*, it is sufficiently distinct to receive a distinct varietal name, and then will appear as *Leptostrophia perplana delthyris* (Con.).

Hall did not recognize the species called by him *Strophomena nervosa*[1] as coming from the Chemung Narrows section; nor does he list it from that section in the final description of the variety.[2] It may therefore be discarded from a strictly diagnostic list.

No. 17, *Spirifer mesistrialis*, in the final description of the species is listed from near Cortlandville in Cortland County. The rocks there exposed are stratigraphically at a lower horizon than Chemung, so that the species will not serve to settle the question as to whether the Chemung fauna is or is not identical with that of the Ithaca member.

No. 18, *Delthyris mesicostalis* Hall. This species was described from a specimen from Angelica, N. Y., and was not reported by Hall from the Chemung Narrows section. The form which has later been identified as of this species, was originally described as *Delthyris acuminata* by Hall; this specific name was dropped because it had already been used by Conrad for a Spirifer. This latter form was recognized by Hall as coming from Ithaca, and Cayuta Creek.[3]

This form (referred to by Hall under the name *Delthyris acuminata*) is a common Chemung species; but the discovery of its intimate association with the Tropidoleptus fauna, its close affinity with Delthyris consobrinus (also a Hamilton species), and its occurrence in the Van Etten and White Church zones of Tropidoleptus entirely below the range of *Spirifer disjunctus*, the Dalmanellas, the Douvillinas, and *Pterinea chemungensis*, has led me to believe that it does not belong to the typical Chemung fauna, any more than do *Tropidoleptus carinatus* and *Rhipidomella vanuxemi*, both of which are abundant in some zones of the section at Chemung Narrows.

Independently, therefore, of the question as to whether there is

[1] *Final Rept. Fourth Dist.* (1843), p. 266, Fig. 1.

[2] *Paleontology*, etc., Vol. IV, 113, 114.

[3] *Report Fourth Dist. N. Y.* (1843), p. 271.

a distinction between the Ithaca and Chemung forms going under the name, this species cannot be regarded as strictly diagnostic of the typical Chemung fauna.

Nos. 19 and 20, *Atrypa spinosa* and *Atrypa reticularis*, are both recorded from lower horizons than the Chemung by Hall in the *Paleontology of New York*,[1] so that they too must be discarded from the list as not strictly diagnostic of the fauna.

DIAGNOSTIC SPECIES OF THE TYPICAL CHEMUNG FAUNA

Excluding the above mentioned species there are left the following eleven species characteristic of the original Chemung group, as expressed in the section at Chemung Narrows a few miles west of the town of Chemung, viz.: *Pterinea chemungensis*, *Leptodesma spinigerum*, *Leptodesma protextum*, *Goniophora chemungensis*, *Mytilarca chemungensis*, *Productella lachrymosa*, *P. lachrymosa lima*, *Stropheodonta* (*Douvillina*) *mucronata* (Van.), *Dalmanella carinata*, *Dalmanella tioga*, *Spirifer disjunctus*. The question may appropriately be raised what is the known vertical range of these species, and how sharply may the Nunda-Chemung boundary be drawn by means of their appearance in the rocks?

Range of the species.—The first species, *Pterinea chemungensis* (*Conrad*), is reported only from this Chemung locality and formation in the *Paleontology of New York*.[2] In that volume several closely allied species are described; in the case of none of the species is a locality or range indicated which would exclude them from this fauna. The species are *Pterinea consimilis* Hall, from Bucks quarry and Chemung, Chemung County, and Smithboro, Tioga County; *Pterinea rigida* Hall, from several localities in Chemung County; *Pterinea prora* Hall, from Bucks quarry and Chemung upper Narrows; also *Pterinea* (*Vertumnia*) *reversa* Hall, and *Pterinea* (*Vertumnia*) *avis* Hall; the subgenus Vertumnia was erected on the character of reversal of the characters of the opposite valves of the shell so that the right valve of Vertumnia appears like the left valve of typical Pterinea The species of Vertumnia are also restricted to the horizons through which the normal species range.

[1] *Op. cit.*, Vol. IV, 1867, pp. 321, 325.

[2] *Op. cit.*, Vol. V, 1884, p. 98.

In the sections examined in the Watkin's Glen quadrangle the range of all these species of Pterinea is restricted to the Cayuta member of the Chemung formation, as defined in this paper, except in a few doubtful cases where the species run higher up than the supposed termination of the Cayuta member into the Wellsburg.

Eastward, in the Harford quadrangle, the species *Pterinea chemungensis* has been discovered at a horizon below the range of the other species of the Chemung fauna. The fauna with which it is there associated is however sufficiently distinct from the typical Chemung fauna to leave little doubt as to a lower horizon. In one case Clarke has reported it at the extreme eastern edge of the Harford quadrangle in association with *Strophedonta cayuta.*[1] Neither of those species has been discovered in the Watkin's Glen quadrangle below the base of the Chemung formation. Clarke also records *Stropheodonta cayuta* in the West Hill sandstone of the Canandaigua and Naples quadrangles[2] and in the West Hill flags and shales of the Watkins and Elmira quadrangles.

While a failure to discover fossils is no evidence that they are wanting, it may be stated that none of the surveying party with the present writer examining the rocks of the Watkins Glen quadrangle has discovered either the *Pterinea* or the *Douvillina* below the stratigraphic base of the Chemung, thus making both of these species a fairly satisfactory evidence of a Chemung horizon for the Watkins Glen quadrangle, though it is not possible to say that they do not appear at a lower level within this province.

Leptodesma spinigerum and *Leptodesma protextum* are recorded from Chemung Narrows and both occur in the Chemung section there. They, however, vary so greatly in form and differ so slightly from the typical *Leptodesma Rogersi;* and there are so many species defined upon slight differences of form, that it will be difficult, without a more exhaustive study than has been given them to use species of this genus in defining the limits of the Chemung fauna. From the fact of the frequent abundance of species of this genus in the zones carrying such other species as *Tropidoleptus carinatus* and *Rhipidomela vanuxemi,* I am inclined to think that they belong to the

[1] *N. Y. State Mus. Bull.* 82, 1905, locality number 2499, pp. 53–70.

[2] *N. Y. State Mus. Bull.* 63, 1904, p. 64.

incursions of the Hamilton species into the region, rather than to the typical Chemung fauna. The Leptodesmas are not abundant in typical Chemung faunules although they are abundant in zones included in the Chemung formation.

Goniophora chemungensis (Van.).—In Hall's monograph on the Devonian Lamellibranchiata[1] this species is recorded from only the localities "Chemung Narrows and near Owego and Binghamton," all of which localities are estimated to be within the same stratigraphic limits, i. e., the Chemung.

In citing the above specific name, it should be noted that the original of the species named *Chemung cypricardite* (*C. chemungensis*) by Vanuxem[2] came from a locality "at the small bridge on the road to Lisle from Binghamton;" and the specimen coming from Chemung Narrows was described under the name *Cypricardites carinifera* by Conrad.[3]

Also, a closely related form was described by Conrad under the name *Cypricardites carinata* from "near Oneonta."[4] This latter specimen is figured on Plate II of the *Fifteenth Annual Report of the State Museum.*[5] Its close resemblance to the form figured by Vanuxem is evident. In fact Hall expressed his opinion that the original of Conrad's species *Cypricardites carinatus* is identical with Vanuxem's *Cypricardites chemungensis;*[6] but in his final monograph (above referred to), he recognized the two species as distinct. Thus in a critical case of identification, when stratigraphic horizon is in doubt, care should be taken to make clear the actual difference in form between the Hamilton form of the genus and the higher one coming from the Chemung. The horizon of the locality from which the original of Conrad's species *Goniophora carinata* came is in dispute. Its association with *Paracyclas lirata* does not prove it to belong to the Hamilton fauna, as pointed out by Prosser.[7] While the species

1 *Paleontology of New York,* Vol. V, Pt. I, ii (1885), p. 303.

2 *Rept. Third Dist. N. Y.* (1842), pp. 179, 181.

3 *Jour. Acad. Nat. Sci.* (1842), Vol. VIII, p. 245.

4 *Fifth Ann. Rept. N. Y. Geol. Surv.* (1841), p. 53.

5 1862, Pl. II, Fig. 21.

6 Hall and Whitfield, *Preliminary Notice of the Lamellibranch Shells,* etc. (1869), p. 34.

7 *Seventeenth Ann. Rept. State Geologist, N. Y.* (1900), p. 80.

described by Conrad as *Cypricardites carinifera* and that named and figured by Vanuxem as *Cypricardites chemungensis* undoubtedly occur at Chemung Narrows in the typical Chemung fauna, the characters by which they may be discriminated from other representatives of the same genus at horizons below the range of other typical Chemung species are too vaguely established to make certain that the species is confined to the Chemung formation. Closely related species of the genus do certainly occur below and probably above the Chemung formation.

Mytilarca chemungensis.—As a genus Mytilarca ranges throughout the Devonian and upward into the lower formations of the carboniferous and both the elongate form *M. chemungensis* and the shorter form *M. carinata* are frequently met with in the Chemung rocks. Several other species have been described from rocks of other than the typical section referred to the Chemung formation. The forms from the Ithaca and lower horizons most closely resembling the Chemung species are more gibbous, and upon this character and the more narrow form of the Chemung representatives of the genus they may be distinguished. So that this species and its closely related species may be used as strongly suggesting, if not strictly indicative, of a Chemung horizon.

One of the localities (2517) referred to by J. M. Clarke in the paper before mentioned as containing *Pterinea chemungensis* is also reported as holding *Mytilarca chemungensis.* Another significant species is *Leptostrophia nervosa.* The combination is one suggesting the Chemung fauna but the horizon is not clear. Clarke reports the locality as "Ithaca beds." [1]

Productella lachrymosa (Con.) and *P. lachrymosa var. lima* (Con.).—There is no doubt that forms of the genus Productella falling strictly under the description of Conrad's species *Strophomena lachrymosa* are present in the typical Chemung zone at Chemung Narrows as well as the variety *S. lima.* The question may be raised, however, whether this species is diagnostic of the Chemung fauna in New York state. Examination of a large number of faunules containing representatives of the genus demonstrate that the prominent characteristics of *P. lachrymosa*, i. e., the ventricose general form, large

[1] *N. Y. State Mus. Bull.*, 82, p. 60.

size for the genus and elongate tubercles scattered sparsely over the surface, become conspicuous at the horizon where the line between Nunda and Chemung is drawn. Nevertheless, specimens occur below this line which might be referred to the species, though they do not express the dominant characteristics of the species at these lower horizons. The dominant forms in the faunules below the line differ either in size, and thus become referable to the species *P. shumardiana* or *P. spinulicosta;* or else differ in the surface markings and fall under the definition of *P. speciosa* in which also the form is less ventricose and the initial umbonal portion is relatively sharper and narrower in relation to the full dimensions of the shell. The Chemung fauna is therefore characterized by the presence of *Productella lachrymosa* and its variety *P. lima*, but on account of the great plasticity of the genus, and the fact that the genus is abundantly represented in the Brachiopod faunules anywhere above the Genesee as at present defined, it cannot be said that the species as defined is strictly diagnostic of a Chemung fauna and horizon.

Stropheodonta (Douvillina) mucronata (Con.).—This species was originally described by Conrad under the name *Strophomena mucronata*, from Chemung Narrows, associated with *Productella lachrymosa.*[1] It was next referred to by Hall under the name *Strophomena interstrialis*. Hall regarded it at that time as identical with Phillips' species of that name.[2] Later Hall described the same species as a new species under the name *Stropheödonta cayuta*,[3] applying the name proposed by Conrad to the form occurring abundantly at Ithaca which had been already well figured by Vanuxem[4] under the name *Strophomena interstrialis*. Hall thus confused under the specific name *mucronata*, both species which he distinguished in the separation of the original figures in his report as 5 and 5*a* from 5*b* and 5*c*, referring the latter two, which present the typical character of Conrad's description to a new specific name *Stropheodonta cayuta*, and applying Conrad's name to the first two of the set which do not offer the distinctive characteristics of Conrad's description. The result,

[1] Conrad, *Jour. Acad. Nat. Sci.* (1842), p. 257, Pl. 14, Fig. 10.

[2] Hall, *Geol. Fourth Dist. N. Y.* (1843), p. 266, Fig. 5.

[3] Hall, *Paleography of New York*, Vol. V (1867), p. 110.

[4] Vanuxemi, *Geol. N. Y. Rept. Fourth Dist.* (1842), p. 174.

which has come to light in noting the subgeneric differences indicated by the names Leptostrophia H. and C. and Douvillina Oehlert, is that the species characteristic of the Chemung fauna of New York, is the one originally described by Conrad from Chemung Narrows. This species belongs to the subgenus Douvillina and is properly therefore named *Stropheodonta* (*Douvillina*) *mucronata* (Con.).

All the faunules collected by the writer's party in the Watkin's Glen and Catatonk quadrangles which contain this species offer no evidence to contradict their reference to the Chemung fauna and Chemung formations as defined in this paper. No case has been discovered by them of the presence of the species at a horizon below the Chemung base. In the two quadrangles 183 faunules have been examined containing this species and of none of them is there any reasonable doubt (either structural or paleontological) as to their stratigraphic position above the Nunda-Chemung boundary as established in this classification.

A faunule from Marathon reservior, R. Ruedemann collector, No. 2499, is reported by J. M. Clarke as belonging to the "Ithaca beds."[1] Although the altitude is not given several of the species named do not indicate a horizon so low as the Ithaca. The species listed are:

Tentaculites sp. incert; Actinopteria eta. (Hall); *Pterinea chemungensis* (Con.); *Grammysia bisulcata* (Con.); *Microdon bellistriatus* (Con.); *Nucula varicosa* (Hall ?); *Palaeoneilo emarginata* (Con.); *P. tenuistriata* (Hall); *P. sp. incert; Schizophoria impressa* (Hall); *Leptostrophia mucronata* (Con.); *Stropheodonta cayuta* (Hall); *Str. cf demissa* (Con.); *Chonetes scitula* (Hall); *Productella lachrymosa* (Con.); *P. sp. incert.; Spirifer mucronatus* (Con.); *S. mucronatus posterus* (H. and C.); *S. mesastrialis* (Hall); *S. laevis* (Hall); *Atrypa reticularis; Cyrtina hamiltonensis var. recta* (Hall); *Pugnax pugnus var. altus Calv.; Leiorhynchus globuliformis* (Van); *Strictopora gilberti; Hederella; Plumalina plumaria* (Hall); *Taxocrinus; Auloprora; Boring sponge; Lepidodendron; Dadoxylon.*

The species whose place in this list seem to the writer questionable are *Pterinea chemungensis*, *Stropheodonta cayuta*, and *Productella lachrymosa*. If these species are correctly identified and occur in association with the other species listed they are not in accord with the evidence gathered by our party at Marathon, and in fact throughout the whole of the Catatonk quadrangle.

[1] *N. Y. State Mus. Bull.* 82, pp. 59 ff.

Dalmanella carinata Hall is described as coming from the localities Painted-Post, Chemung, and Jasper[1] under the name *Orthis carinata.* But in the final description of the species[2] it is referred to Painted-Post alone. The statement is made that it "has not been obtained from any other locality,"[3] and we are told that in many of its characters this species assimilates with *Orthis tioga* and one of the localities from which *Orthis tioga* is cited is Chemung Narrows. Hence we may infer that the species selected as typical of the Chemung Narrows section is *Orthis tioga,* and although *O. carinata* has been discovered there, Hall evidently changed his opinion as to the Chemung Narrows form while the final report on Paleontology was being prepared.

Dalmanella tioga Hall.—This species was originally described and figured by Hall[4] under the name *Orthis interlineata* Sowerby. It was later described by him under the name *Orthis tioga.*[5] Still later it was placed by Hall and Clarke in the genus *Schizophoria* King.[6] And in the year 1905 the characters of the species were shown by Williams to be those of the genus *Dalmanella,* not Schizophoria.[7] It was pointed out by Williams that in Schizophoria the pedicel valve is resupinate, and, in the upper Devonian forms, presents a distinct sulcus along the center of that valve. The pedicel valve of Dalmanella on the other hand is distinctly elevated into a fold or narrow ridge, and in that genus the valve with the sulcus is the brachial valve, which is always convex in Schizophoria. There are other internal characters to separate the two genera, but the above external characters are sufficiently large and conspicuous to be detected in the field and furnish the evidence of the genus Dalmanella, by which presence of the Chemung fauna may be established for this province. The genus was prominent in the Ordovician and Silurian and appears conspicuously in the lower Helderberg. The only report of the genus

[1] *Geol. N. Y. Rep. Fourth Dist.* (1843), p. 267, Fig. 1.

[2] *Paleontology of New York,* Vol. IV (1867), p. 58, Pl. 8, Fig. 30–32.

[3] *Loc. cit.,* p. 59.

[4] *Geol. N. Y. Rept. Fourth Dist.* (1843), p. 268, Figs. 3, 4.

[5] *Paleontology of New York,* Vol. IV (1867), p. 59, Pl. VIII, Figs. 20–29.

[6] *Op. cit.,* Vol. VIII, Pt. 1, 1892, pp. 212, 226, Pl. VI, Figs. 17, 18.

[7] *U. S. Geol. Sur. Bull.* 244 (1905), p. 86.

from the Hamilton is the case of the minute species *Dalmanella lepidus* Hall, reported to have been found in only a single locality on the shore of Canandaigua Lake, Ontario County, N. Y., and in few individuals.[1] In the great number of faunules gathered and examined from the sections now under investigation and the neighboring regions of the Watkins Glen and Catatonk quadrangles not a trace of the genus Dalmanella has been seen below the Nunda-Chemung boundary line (i. e., not in the Nunda, Ithaca, Genesee, or Tully formations). In the Chemung rocks, however, the genus is represented by at least three species, and in some zones abundantly.

The species *Dalmanella tioga* is common and often met with in the Chemung rocks of this section from a horizon, 100 feet above the base upward for five hundred feet where it becomes less frequent.

In the first one hundred feet it is represented by the smaller species *Dalmanella leonensis*, which in some zones is abundant; but this species has not been recognized in this region above about one hundred feet from the base of the Chemung formation.

The genus has been observed in seven faunules from the Watkins fifteen-minute quadrangle. In all these cases the faunules present other indications of a horizon at the base of the Chemung and the line has in all cases been drawn to include the genus in the Chemung formation.

In the Elmira quadrangle the genus has been observed in fifty-one faunules, and in all of them the evidence, on other grounds, leaves no doubt as to the Chemung horizon of the strata containing them.

Twenty-nine faunules from the Ithaca quadrangle are equally clear as to the stratigraphic horizon to which the species of this genus belong.

From the Waverly quadrangle eighty faunules contain one or other species of the genus, and regarding none of them is there doubt as to the stratigraphic horizon to which they belong.

From the Dryden quadrangle fifteen faunules hold representatives of the genus.

In the Owego quadrangle the genus has been seen in seven faunules.

In the Apalachin quadrangle three cases have been recorded;

[1] *Paleontology of New York,* Vol. IV (1867), p. 46.

but no faunule has been discovered in the Harford quadrangle containing a species of Dalmanella.

Clarke cites no case of a Dalmanella in the list of species recorded from Central New York in the Ithaca fauna.[1] I have not observed in the various papers written by C. D. Prosser any report of a species of Dalmanella (or a species recorded under the name Orthis, now known to be Dalmanella) from the Devonian of Chenango Valley or further east in New York State, except the one case of *Orthis lenticularis* Van., from Chapman's Quarry, Babcock Hill, which is a typical Corniferous limestone.[2]

These facts indicate that eastward of the Ithaca meridian Dalmanella rapidly becomes rare and is rarely seen in Upper Devonian faunas beyond the Apalachin quadrangle eastward.

Tracing the evidence westward Clarke cites the species *Orthis infera* Calvin, which is a Dalmanella, from the fauna of the High point sandstone of Naples.[3] This species is small and closely related to *Orthis leonensis*. From the same fauna are cited also *Stropheodonta cayuta* and *Spirifer disjunctus*, thus leaving no doubt as to the Chemung character of the fauna.

In the Genesee Valley the genus is frequently met with in association with typical Chemung faunules.[4] In only one case in that bulletin is it reported from a doubtful horizon. This is the case of the shales at Hornellsville, Station No. 494. Here it occurs with *Cardiola (Buchiola) speciosa* and other species of the Nunda fauna. It is followed immediately by beds carrying *Spirifer disjunctus*. The species there is *Dalmanella leonensis*. This, with our present knowledge, locates the Hornell horizon in the *Dalmanella leonensis* zone at the base of the Cayuta member of the Chemung. A similar association takes place in the early faunules of the Watkins Glen and Elmira quadrangles, which indicates an over-lapping of the Nunda species upon the first incursion of the Chemung fauna. Still farther west in Chautauqua County the earlier Chemung faunas

[1] "Ithaca Fauna of Central New York," *N. Y. State Mus. Bull.* 82, pp. 53–70.

[2] "Devonian Section of Central New York," *N. Y. State Geol. Twelfth Ann. Rept.* (1894), p. 5.

[3] *N. Y. State Mus. Bull.* 63, p. 64.

[4] *U. S. Geol. Survey, Bull.* 41, pp. 30, 67, 69, 74, 76, 80, 85.

contain the smaller form of the genus called *Orthis* (*Dalmanella*) *leonensis*.

In the Chemung rocks of western New York the genus is almost as conspicuous as *Spirifer disjunctus* or *Orthothetes chemungensis*.

Taking in all the evidence the conclusion is drawn that Dalmanella is a characteristic genus throughout the whole Chemung in the western New York section; is more rarely present in the faunules of Genesee Valley; is conspicuous in the early and middle zones of the Chemung in the sections of Watkins Glen quadrangle; is rare in the Catatonk quadrangle, and is rarely ever seen further eastward.

The species *Orthis* (*Dalmanella*) *tioga* Hall,[1] was described from specimens derived near Factoryville in Tioga County, along Cayuta Creek, at Chemung Narrows, near Elmira, at Horseheads, and at Bucks quarry. It was also obtained from Allegany County at Phillipsburg, and near Leon and other places in Cattaraugus County, N. Y.

The species *Orthis* (*Dalmanella*) *leonensis* Hall,[2] is a smaller species and in the original description it is cited only from the Chemung group near Leon, Conewango and Randolph in Cattaraugus County, N. Y.

The Dalmanella leonensis zone.—Investigations into the range of the species of the genus in the Watkins Glen thirty-minute quadrangle show that the small form *Dalmanella leonensis* is confined to the lower one hundred feet (or a little over) of the Cayuta member of the Chemung formation. As it is often quite abundant in that zone the name *Dalmanella leonensis zone* is appropriately applied to it.

Common associated species of the faunule are: *Leptostrophia interstrialis; Productella spinulicosta; Spirifer disjunctus; Reticularia laevis; Palaeoneilo brevis; Pterinea chemungensis.*

Above the zone of *Dalmanella leonensis* the species *D. tioga* appears and in the sections along the meridian of Ithaca ranges upward through the Cayuta and Wellsburg members of the Chemung formation.

Spirifer disjunctus (Sowerby) may be regarded as a diagnostic species of the Chemung formation throughout New York state and its extension into Pennsylvania, Maryland, and Virginia. There are cases

[1] *Paleontology of New York*, Vol. IV (1867), p. 59.

[2] *Op. cit.*, Vol. IV (1867), p. 62.

of report of the species from rocks believed to be of a lower horizon than Chemung, but in several doubtful cases of this kind investigation has shown the absence of any conclusive evidence that the species was actually derived from the horizons mentioned.[1] In all cases in which the evidence is at hand for critical study no fauna containing authentic specimens of *Spirifer disjunctus* has been seen in New York or adjoining territory which upon any other kind of evidence can be satisfactorily thrown into a stratigraphic horizon below the base of the Chemung formation.

Many other species than those above mentioned have been listed from the Chemung formation, and they also may be recognized as good Chemung species; but it is important here to determine which particular species are diagnostic of the typical Chemung fauna, in order to establish an exact standard from which to trace the formation beyond the locality of its original definition.

In drawing the lines for the Watkins Glen quadrangle map the base of the Chemung formation has been discriminated by means of the above listed species. The formation line is thrown down as low as any of these diagnostic species have been certainly detected. This line has proven to be drawn consistently with the observed stratigraphy and conforms to the structural facts. This revision puts the line stratigraphically higher by some two hundred feet than I located it in 1884.[2] The faunule of Station No. 58 of that paper contains a species of Productella which I then identified with *P. lachrymosa*, and also the following species: *Ambocoelia umbonata* var. *gregaria*, *Orthis impressa*, and *Atrypa reticularis*. The faunas listed as 62*a* and 62*b* contain *Lingula complanata* and *Spirifer* (*Delthyris*) *mesicostalis*. All these are now thrown below the base of the Chemung, because of absence in them of the diagnostic species above cited.

The Van Etten Zone of Tropidoleptus.—The portion of the column thus thrown down from the Chemung into the upper part of the Nunda

[1] See Prosser, "The Devonian System of Eastern Pennsylvania and New York," *U. S. Geol. Survey, Bull.* 120 (1894), p. 12; Also Williams, "On the Formational Correlation of the Catawissa Section," in *Contributions to Devonian Paleontology, U. S. Geol. Survey, Bull.* 244, pp. 78 ff., 1905.

[2] "On the Fossil Faunas of the Upper Devonian," *U. S. Geol. Survey, Bull.* 3, p. 21.

upon paleontological evidence has been called the Van Etten zone of *Tropidoleptus*, for the expression of it seen in the rocks about Van Etten near drainage level. It was not known to contain *Tropidoleptus* in 1886, when I published the paper on the classification of the Upper Devonian.[1] Since then the fauna has been detected in several places. When well developed it contains the following species: *Tropidoleptus carinatus; Rhipidomella vanuxemi; Productella spinulicosta; Ambocœlia umbonata; Lingula complanata; Spirifer marcyi; Delthyris mesicostalis.*

Specimens of the latter species in external appearance are often very similar to the ordinary type of *Spirifer mucronatus* (= *pennatus*) of the Hamilton group.

Associated with these diagnostic species the fauna also contains species of the following genera, viz: Leiorhynchus, Leptodesma, Palaeoneilo, Grammysia, Modiomorpha (Cypricardella is not generally with it), Bellerophon, Coleolus, Pleurotomaria, Loxonema, Platyceras and occasionally Orbiculoidea, Chonetes and Camarotoechia.

One of the best places to see the fauna is in the ravine above White Church in the Dryden quadrangle, where it lies about two hundred feet below the base of the Chemung. On passing eastward the rocks of the upper part of the Nunda become more and more fossiliferous, and other species come in and probably other zones of the Tropidoleptus fauna; but in the Watkins Glen quadrangle this fossiliferous zone is frequently seen in the more eastern sections below the typical Chemung fauna, carrying several species which are common above, but never any of the species indicated above as diagnostic Chemung forms.

In the sections about Ithaca, traces of this same fauna are seen near the base of the Ithaca member in the zone I referred to in 1882[2] as a recurring Hamilton fauna. Since that paper was written the *Tropidoleptus carinatus* has been noted at the same horizon.

When these recurrences take place in the Watkins Glen quadrangle below the range of *Delthyris mesicostalis*, but above the Hamil-

[1] *Proc. A. A. A. Soc.*, Vol. XXXIV (1886), pp. 222 ff.

[2] "The Recurrence of Faunas in the Devonian Rocks of New York," *Proc. A. A. A. Soc.*, Vol. XXX (1882), p. 189.

ton, the horizon is (recognized as) in the Ithaca member of the Nunda; when the *Delthyris* is associated with them, but below the place of first appearance of the diagnostic Chemung species, the horizon is upper Nunda: i. e., the Van Etten zone of Tropidoleptus. Still later, after the Chemung species were upon the ground, in the lower part of the zone of *Dalmanella tioga*, Tropidoleptus again occurs. It is this third stage of its recurrence that was referred to in the list of species given on p. 24, of Bulletin No. 3 of the U. S. Geological Survey. It was numbered A^6+ and called "the second recurrence of the Tropidoleptus stage" in my paper on the classification of the Upper Devonian in 1886.[1]

The line thus determined as the horizontal boundary between the Nunda and the Chemung is traceable eastward as well as westward, by the range of the fossils which furnish a definite paleontologic means of discriminating the Chemung formation throughout its geographic extent.

The references to Dalmanella in *Contributions to Devonian Paleontology* of 1903[2] have been re-examined critically in the light of these investigations. All the citations of *Dalmanella tioga* and *D. carinata* are correct and the horizons containing them are unmistakably Chemung. The reference to the species *Dalmanella tenuilineata*, on p. 33 faunule 1379B, is based on a single specimen, and the species is the one described by Hall under the name *Orthis leonensis*.

The specimens identified, on pp. 36 and 37, as *Dalmanella tenuilineata* (from faunules $1380B^6$ and B^7) are in both cases associated with *Spirifer disjunctus* leaving no doubt as to the horizon, but they are specimens of a small Schizophoria and should not be referred to the genus Dalmanella. The specimen identified as Dalmanella in faunule $1453A^3$ on p. 70, does not exhibit the characteristic features of Dalmanella.

In using the faunal method of determining the boundary line between the Nunda and Chemung the assumption is made that a faunal distinction was applicable to the Chemung group as originally defined by Hall. This assumption is borne out by the later experience of paleontologists in finding distinct evidence of this fauna in

[1] *Proc. A. A. A. Soc.*, Vol. XXXIV (1885), p. 226.

[2] *U. S. Geol. Survey, Bull.* 244 (1905).

widely diverse regions of the United States. The attempt is made in the present discussion by close analysis of the fauna at the typical locality, to ascertain the particular species whose appearance in the strata begins at a definite horizon. This analysis has furnished the practical basis for drawing the line across the Watkins Glen quadrangle.

In order to explain the fact of such a definite change in the fauna at such a boundary line, it has been necessary to assume an incursion of the Chemung fauna from outside into the region at a particular point of time. Thereafter, for a considerable length of time, the species of fossils represented in the rocks were of the same fauna and constitute the typical Chemung fauna.

However, it must be distinctly remembered that such an assumption involves the pre-existence of the fauna in full vigor prior to the time of its incursion into this region.

If we were to assume that the species of the Chemung fauna were directly evolved from species living in the same region when the underlying rocks were being deposited, the sharpness of the line would necessarily be lost and no definite boundary horizon could be drawn on the basis of fossil faunules alone; for the reason that the change in specific character does not take place at such a rapid rate that the differences could be detected.

It is therefore considered to be a confirmation of the hypothesis of incursion of the fauna that the stratigraphic line marking the first appearance of the chief diagnostic species of the Chemung fauna occurs at a horizon so consistent with the general structure of the strata of a thirty-minute quadrangle. Another confirmation of the theory comes from the geographical extension of that horizon. On passing westward from the Ithaca meridian the line of separation of the faunas becomes more sharp and distinct; while on passing eastward the fauna below the line contains more and more species which are also found above the line.

In this eastern extension of the line, however. the distinctive Chemung species become less dominant and as has been shown in earlier papers, the reappearance of species, which in the western New York outcrops are confined to horizons far below the boundary, is observed to be the rule rather than an occasional exception.

We are thus forced by the study of the facts, to the opinion that the horizon which is thus drawn on the basis of a change of the fossil faunas in the strata, while it represents at any one spot a definite point in geologic time, does not represent the same point of time in the sections of separate regions.

We are warned by the reappearance of many of the species of the Independence shale of Iowa in the fauna at the top of the Iowa Devonian series (Lime Creek shales), against the assumption that the same horizon is always indicated by the same fauna.[1] Correlation by faunas is always subject to the criticism that the mere presence of a fossil indicates only some point of time during the life history of that species. Nevertheless, in a restricted region, such as the one now under investigation, the first appearance in the stratigraphic column of a definite fauna, defines a definite geologic horizon with a high degree of precision. And so long as correlations are extended from the typical outcrop within the same geologic basin, the transition from one fauna to the next higher may be depended upon as marking the same point in the faunal histories whether they be considered as synchronous or only homotaxic.

[1] Calvin, *Iowa Geol. Surv.*, Vol. VIII, p. 222.

ABRASION BY GLACIERS, RIVERS, AND WAVES

LEWIS G. WESTGATE
Ohio Wesleyan University, Delaware, O.

INTRODUCTION

Erosion[1] or land sculpture includes rock disintegration, where the rock is coherent, and transportation of the material disintegrated. Disintegration has been divided into weathering and corrasion. Stream- and wave-wear may be either chemical or mechanical, though in all ordinary circumstances the mechanical wear is so much greater than chemical solution that the latter may be neglected. Ice-wear is purely mechanical. Omitting chemical solution, which is an entirely distinct process, corrasion may be defined as the mechanical wear performed by wind, streams, waves or glaciers. Gilbert[2] uses the term "corrasion," excluding chemical corrasion, for the "mechanical wear . . . . performed by the aid of hard mineral fragments which are carried along by the current." Chamberlin and Salisbury[3] define stream-corrasion as "the wear effected by running water." This use of the term is wider than that of Gilbert, for it includes not only wear by tools, but also the process of sweeping away material which has always been incoherent and "material loosened in advance by the process of weathering." To distinguish these radically different processes of stream-action, in this paper the term "abrasion" will be used for the mechanical wear performed by tools, and "plucking" for the removal of rock fragments. "Corrasion," including all mechanical wear by streams, will include both abrasion and plucking. None of the terms are new; they have more or less overlapped in use, and it is believed that the meaning here assigned to them is that generally understood today. The terms can be applied to glacier- and wave-action with the same significance with which they are

[1] Gilbert, *Geology of the Henry Mountains*, pp. 99–102.

[2] *Ibid.*, p. 101.

[3] Chamberlin and Salisbury, *Geology*, Vol. I, p. 113.

applied to stream-action. The analysis of erosion by waves, glaciers, and streams, would be arranged as follows:

$$\text{Erosion} \left\{ \begin{array}{l} \text{Rock-Disintegration} \left\{ \begin{array}{l} \text{Weathering} \\ \text{Corrasion} \left\{ \begin{array}{l} \text{Abrasion} \\ \text{Plucking} \end{array} \right. \\ \text{Solution} \end{array} \right. \\ \text{Transportation} \end{array} \right.$$

In geological literature abrasion is ordinarily considered an important factor in land sculpture. It is the purpose of this article to suggest that abrasion by glaciers, streams, and waves is in most cases a negligible factor in erosion, and to emphasize the importance of weathering in the work of erosion by streams and waves. Wind-erosion is not considered.

GLACIAL ABRASION

The common understanding of glacial erosion has been that it is accomplished by the wear of solid particles held in the bottom of the ice against the rock surface over which the ice moved. This process would be favored by the weight of the glacier and by the fact that particles so held are often in continuous contact with the bed-rock for long distances. If this process were the only or the chief factor involved in glacial erosion, the rasplike action of the broad glacier bottom should produce a smoothed, sub-even surface. Within the glaciated area of North America there are many nearly level, glacially smoothed surfaces, but these are in regions which were level in preglacial times, and are areas which there is reason to believe were not deeply eroded. In the hilly regions of glaciated North America and in glaciated alpine valleys the detail of such surfaces is. controlled by rock jointing, and glacial abrasion is limited to smoothing the surfaces and rounding the corners of the joint blocks. This hackly character of the topographic detail of surfaces covered by the Pleistocene ice-sheet may be in part an inheritance from pre-Pleistocene time, but in glaciated alpine valleys (see Fig. 1), having lateral hanging valleys, the rounded-hackly surface of the lower part of the main valley has been produced by the normal action of glacial erosion in live rock, scores and perhaps hundreds of feet below the original surface. Here plucking, or the removal of large blocks bounded by joint planes, has been the important element in erosion.

Before glacial abrasion has been able to smooth away the inequalities produced by plucking, the process of plucking has produced new inequalities. The effect of abrasion in wearing down the valleys is neutralized by the removal of the joint blocks when only partly abraded. It has been a pluck-and-heal process, with plucking always ahead. It is not a question here whether the blocks plucked are removed mechanically by the ice, or are loosened by subglacial weathering; the point emphasized is that valley-deepening does not take place through scratching by material carried in the bottom of the ice.

FIG. 1.—Joint-controlled glacially eroded surface. Direction of ice-movement was to left. The view shows the inability of abrasion to obliterate the control, by jointing and plucking, of the surface form. Lake Creek, above Twin Lakes, Colo.

There is nothing new in this statement of the process of glacial erosion. Plucking is recognized more and more. The relative incompetency of glacial abrasion is mentioned here because it leads up to the consideration of the inadequacy of stream-abrasion. The same class of facts is appealed to for evidence in both cases, and these facts have been recognized much more widely in the case of glacial erosion than in that of stream erosion.

STREAM-ABRASION

Stream-abrasion has generally been considered an important element in valley-cutting. It was clearly distinguished by Gilbert[1] and recent texts usually consider it, though no attempt has ordinarily been made to indicate the relative importance of abrasion, plucking,

[1] Gilbert, *Geology of the Henry Mountains*, p. 101.

and weathering. Chamberlin and Salisbury[1] go as far as any recent text in emphasizing the importance of weathering and plucking, and so in limiting the relative importance of abrasion in valley-cutting. They say that in any valley cross-section the amount removed by corrasion may be measured by a rectangle the width of which is the width of the stream, and the height of which is the depth of the valley. It seems, however, that even this relatively small proportionate amount, while allowed to the stream, must be denied to stream-abrasion, and divided between plucking and weathering.

Theoretically stream-abrasion is less probable than abrasion by glaciers. The cutting particles are not held against the rock bottom by any overlying mass of ice; indeed, the weight of the particles is lessened by their immersion in water. The smaller particles are largely carried in suspension, striking the bottom only at intervals. Fragments too large for suspension move over the bottom with rolling and not with sliding friction.

The form usually shown by the rock-bed over which the stream flows bears evidence to the inadequacy of mechanical wear of detritus in shaping it and in lowering the bed. The Olentangy River below Delaware, O., for example, is flowing over nearly horizontal beds of Devonian limestone. The bed of the river, which has since glacial time been cut a dozen feet into the hard rock, consists of a succession of very broad, low steps, each step being a limestone stratum, its down-stream limit determined by vertical joint-faces. In some places the edges, and in a few places the surfaces, of these steps are slightly rounded, as if by mechanical wear; but this in no way affects the large fact that the rock in the stream-bed is bounded by stratification- and torsion-joint planes. The agency effective in removing the rock from the stream-bed has taken it away in large blocks; the rock has not been scratched away by the mechanical rubbing of fragments swept down by the stream. The ordinary processes of weathering are believed to have loosened the jointed limestone, and the blocks were later swept away by the stream. As in the case of glacial erosion, before abrasion could reduce a joint-block, weathering processes isolated the partly worn block, and delivered it to the

[1] Chamberlin and Salisbury, *Geology*, Vol. I, p. 108.

stream for removal. In each case the character of the bottom bears evidence to the ineffectiveness of abrasion.

This fact in regard to the form of the stream-bed has been noticed by the writer in the streams cutting the Ohio shale and Cincinnati limestone (see Fig. 2) in Ohio, in the sandy shales near Ithaca, in the Berea sandstone of Ohio, in the Triassic sandstone along the lower Westfield River and the Connecticut River, and in the crystalline rocks along the upper Westfield River. Views showing stream-beds, notably the collection in Tarr's *New Physical Geography*, give evidence in the same direction.

FIG. 2.—Stream in thin-bedded Cincinnati limestone, in which the characteristic irregular surface of the stream-bed, the result of plucking rather than abrasion, is shown. Near Camden, O.

In qualification of what has just been said in reference to stream-abrasion, two things may be mentioned. First, reference should be made to pothole action. It is abrasion, and where numerous potholes are forming and connect, they may decidedly aid downward erosion. This action, however, is believed to be exceptional; the great majority of streams are without it. Secondly, and forming a really important exception, in certain cases streams are flowing over rock-beds which are thoroughly smoothed, and appear to have been deepened by wear of stream-swept detritus. In these cases it is believed that it will be found that the rock is nearly jointless. This is especially the case with crystalline rocks, particularly the more massive granites. This process of wear by abrasion is most common in swift streams in mountainous areas, but even here it is exceptional, and in the consideration of stream-erosion generally it is insignificant.

In conclusion, the joint-controlled form of the rock sides and

bottoms of stream-beds shows that abrasion has not been a determining element in valley-deepening, and that the stream is a transporting and not an abrading agent, removing materials dislodged from its bed or swept into it from its valley sides.

WAVE-EROSION

As in river-erosion, so in wave-erosion, abrasion, or the wear by material thrown against the base of the cliff, has been generally emphasized in the texts. Chamberlin and Salisbury[1] make corrasion by the impact of detritus an important element in wave-erosion on hard rocks, at the same time emphasizing the co-operation of weathering along joint planes. Geikie[2] says: "The waves make use of loose detritus within their reach to break down cliffs exposed to their fury. Probably by far the largest amount of erosion is thus accomplished." Le Conte[3] says that "fragments hurled against the shore are the principal agent of wave-erosion." But if abrasion has been the determining factor in wave-cutting, the shore in the vertical zone of breakers should bear evidence of this by its rounded and worn character.

FIG. 3.—Shore on the east side of Easton's Point, Newport, R. I.

The only chance which the writer had to study rock shores with this consideration in mind was at Newport. In the hard conglomerate and sandstone at Easton's Point (see Fig. 3), on the south side of the island, no evidence of abrasion was found. To be sure, in some protected pockets, into which gravel had been swept

[1] Chamberlin and Salisbury, *Geology*, Vol. I, pp. 327–29.

[2] Geikie, *Text-Book of Geology*, Vol. I, p. 569.

[3] Le Conte, *Elements of Geology*, 5th ed., p. 34.

by the waves, the roll of the gravel had smoothed the solid rock; but elsewhere the waves are breaking either on surfaces which have not been appreciably eroded, or on a rocky shore composed of angular masses of rock of all sizes, which have been loosened by weathering. Wherever the shore is being worn, it is by combined weathering and plucking, and not by abrasion. Easton's Point is not yet marked by a wave-cut cliff, and so is not the best place to show the process of erosion; but along the Cliff Walk, at the west end of Easton's Beach, where the rock is prevailingly Carboniferous schists, a distinct cliff faces the ocean; the base of the cliff, however, is not rounded and smoothed as would be the case were it being worn back by abrasion. A very suggestive photograph of a raised wave-cut bench on Prudence Island has been published,[1] in which both cliff and bench are rough and angular, the detail determined by the jointing of the shales.

It will be easy, of course, for anyone to test the matter for himself. Detritus protects rather than endangers the cliff. Except at times of high storm, the beach material protects the cliff and acts on itself. It does not seem probable that the bombardment of the cliff at times of heavy storm would seriously affect the cliff. Certainly there is little evidence of such action in the detail of the cliff base. Waves acting by hydrostatic pressure along joint planes may be effective; apart from that action their work would appear to consist in reducing and removing materials supplied them by the processes of weathering. They, like streams, are transporting and not abrading agents.

RELATIVE IMPORTANCE OF PLUCKING AND WEATHERING

The mechanical work of corrasion has been divided between abrasion and plucking. Abrasion does not appear to be an important factor. It is further a delicate question as to how far plucking can be considered a separate process, to be distinguished from weathering on the one hand and transportation on the other. In the case of glacial erosion it is easy to believe that the pressure of the ice may dislodge blocks from a jointed floor which has not been affected by weathering, though it would be difficult to show that frost-weathering had not had a share in loosening these blocks. It is possible that a

[1] *Geology of the Narragansett Basin,* Monograph 33, U. S. Geological Survey, Plate XXIII.

similar effect may be produced on the sea-cliff in time of heavy storms. But the impact of storm-waves even would seem to be less effective than the pressure of glacial ice, and the fact that the cliff base is exposed to the air, and is often, and in some cases always, water-soaked, indicates that the loosening of the rock fragments which are finally dislodged by the waves is in reality the result of weathering. In the case of streams flowing over jointed coherent rock, it is difficult to believe that even the swift currents of flood seasons are able to dislodge rocks from the stream-beds. The impact of the water is too slight, and is exerted on the nearly flat stream-bed at a great disadvantage. The stream is able to sweep away blocks, not too large, which have been loosened and partly dislodged by weathering; but it is not easy to believe that the stream is the dislodging agent.

If, as seems certain in the case of stream-erosion, and as seems probable in case of wave-erosion, the loosening of the rock fragments is the result of weathering, then plucking becomes merely the first step in the transportation of débris, and is reduced to a vanishing quantity between weathering and transportation. In that case the stream becomes a transporting and not a corrading agent; weathering becomes the important factor in valley-deepening as in valley-widening; while the stream acting as a transporting agent prevents the process from clogging. To the extent that weathering replaces plucking by wave-action, the same thing is true of shore erosion. In glacial erosion only is plucking left as a large factor, and even here it is not certain that it is the only factor in joint-block removal.

THE SKULL OF PALEORHINUS

A WYOMING PHYTOSAUR

J. H. LEES
The University of Chicago

The University of Chicago paleontological expedition to Wyoming during the summer of 1904, under the direction of Dr. S. W. Williston, secured several phytosaurian skulls in excellent preservation. These skulls together with other fossil remains were collected from the Popo Agie beds of the Upper Trias of the Wind River region. One of these, made the type of a new genus by Dr. Williston and given its specific name in honor of its finder, Dr. E. B. Branson, has been studied by the writer during the past winter and the results of the work are here published. A preliminary announcement of the characters of this specimen, together with notes regarding the other specimens found at the same time, was issued some time ago by Dr. Williston (this JOURNAL, Vol. XII, 1904, p. 696).

General characters.—Skull greatly elongated, triangular; snout long, slender, depressed. External nares elevated, situated at posterior extremity of snout, entirely in front of antorbital vacuities, separated by downward extensions of nasals. Antorbital vacuities large; supratemporal vacuities small, completely enclosed; otic foramina present and completely enclosed. Quadrate foramina present, small. Squamosal extending but slightly beyond posterior margin of quadrate. Median notch of skull nearly in shape of isosceles triangle; notch above quadrate moderately deep. Plane of orbits directed obliquely upward.

Internal nares situated posterior to external, separated by vomers. Palatines separated by pterygoids. Vomers long and slender, separating pterygoids throughout, extending back to presphenoidal opening. Pterygoids long, entering into posterior margin of nares between palatines and vomers, extending postero-laterally in broad vertical plates for union with quadrates. Basipterygoid processes moderate in size, enlarged distally.

Posterior palatine foramina small, wholly enclosed by palatines and transverses. Presphenoidal opening small, cordiform. Teeth thirty-six on each side of upper jaw, two foremost larger and much elongated.

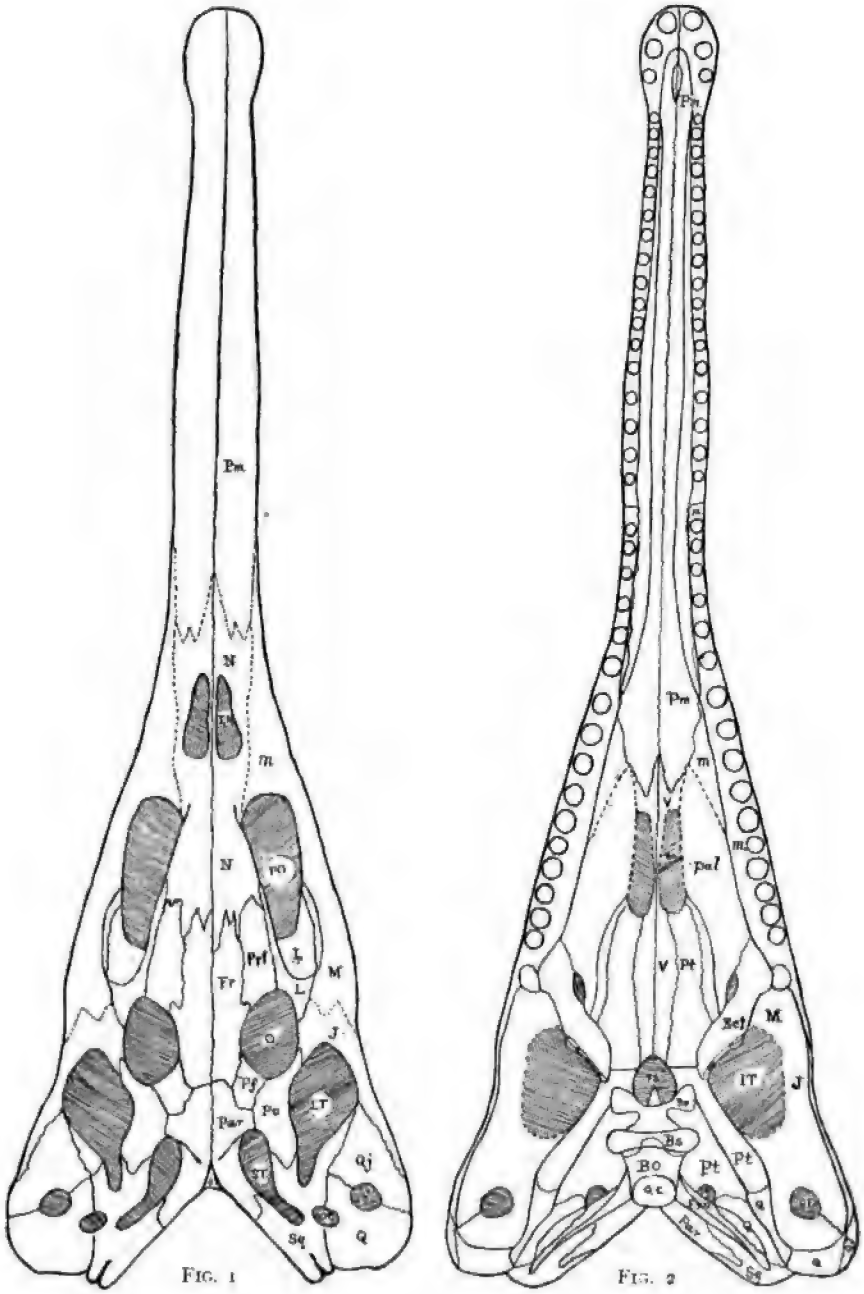
Mandible presenting high surangular crest and short posterior extension. Inner face bearing a strong, subrectangular process which springs from posterior extremity and extends anteriorly parallel to the ramus. Jaw rather slender, pierced by external and internal fenestræ and by small internal mandibular foramen.

Ilium bearing on outer face three strong ridges meeting in a high central knob above acetabulum. Posterior extremity continued in long process. Inner surface quite smooth except for long shallow trench for reception of sacrum, and two ill-defined ridges which bound it.

The skull is quite broad in the occipital region and narrows gradually to the region of the nares. A short distance in front of these the roof slopes downward and merges into the snout, which comprises about one-half the length of the entire skull. The snout is depressed and in cross-section its width is greater than its height. At the anterior extremity it is enlarged and somewhat deflected downward, and bears two large teeth on each side.

Viewed from the side the skull appears rather depressed, as its elevation is about one-half its greatest width. It presents a fairly even crest-line from its posterior margin to a position somewhat in front of the middle of the antorbital vacuities, where it begins to rise to the elevation upon which the nares open. From the nares the slope downward to the snout is rapid.

In the side view nearly all the external openings of the skull are visible—the anterior, excavated portion of the nares, the antorbital vacuity, the orbit itself, the lateral temporal vacuity, the quadrate foramen, and the opening of the otic capsule together with the small notch immediately beneath it. Only the supra-temporal vacuity and the deep median notch remain concealed. The skull is thus given quite a light, open appearance and has a much less massive aspect than some of the related belodonts, especially *B. kapffi*—or *Phytosaurus kapffi*, to follow McGregor—although this contrast is rendered more forcible by the slender snout of the specimen in



Skull of ***Paleorhinus bransoni*** Williston.

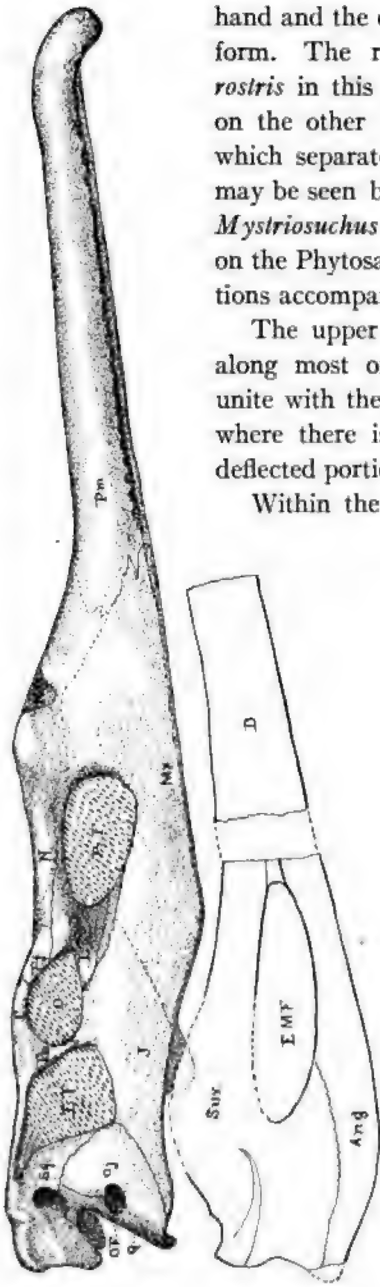


FIG. 3.—Skull of *Paleorhinus bransoni*, from the side.

hand and the enlargement of that in the European form. The resemblance to ***Mystriosuchus planirostris*** in this respect is much closer, but there are on the other hand some very marked divergences which separate the two individuals rather widely, as may be seen by a comparison of the illustrations of *Mystriosuchus* as given by McGregor in his paper on the Phytosauria. See bibliography and illustrations accompanying this paper.

The upper line of the snout is almost straight along most of its length, except where it rises to unite with the skull and also in the anterior region where there is a slight convexity just behind the deflected portion.

Within the line of the dental alveoli is a strong rounded ridge which probably meets a corresponding ridge on the mandible, as is stated by McGregor to be the case in *Mystriosuchus*, and thus prevented too forcible meeting of the teeth. These latter must have pointed obliquely outward.

The lateral bones of the skull are slightly roughened by irregular pittings and rugosities. This feature becomes more marked on the bones of the roof, especially on the frontals, where, between the anterior portions of the orbits, is a small area of very notable rugosity. Just anterior to this area the frontals are sculptured by narrow longitudinal ridges and furrows about one-eighth inch in width and one-half as deep, and with lengths up to one inch or more. The region between the antorbital vacuities is again roughened by small irregular tubercles and the

narial region is marked by small irregular pits and elevations, while the snout is rather smooth, with ornamentation about like that of the lateral portions of the skull.

Premaxilla.—The premaxilla is greatly elongated and makes up the entire rostrum except that portion immediately surrounding the nares. This part of the skull is, however, so shattered that the sutural relations of premaxilla, maxilla, and nasal cannot be determined with accuracy. Judging from von Meyer's figures of *Belodon* the premaxilla should extend to within about two inches of the nares, while the maxilla extends forward about two inches under the premaxilla. The indications point to this being the case. If this is true it gives the premaxilla a length of about fourteen and one-half inches.

The two premaxillæ were never fused; the suture remained distinct throughout life, and the union of the bones was so slight that the post-mortem crushing of the skull has caused them to slip over one another for almost one-half inch in one place.

Maxilla.—There seems to be a suture extending from a little in front of the middle of the upper border of the preorbital vacuity forward and slightly upward till it reaches a point opposite the middle of the naris, whence it descends rapidly, about parallel with the upper line of the snout, until it reaches the margin of the jaw about six inches in front of the point of its origin. This would be the union between the maxilla and the nasal for about four inches and between the maxilla and premaxilla for the anterior two inches. How far the maxilla extends backward and where it unites with the jugal cannot be positively stated, though by analogy with the European forms the union should be on that part of the cheek between the antorbital and lateral temporal vacuities. The maxilla lies below the lachrymal behind the antorbital opening and is united with that element for about two inches. Here it probably meets the jugal—about under the middle of the orbit. This would give to the bone a length of between eleven and twelve inches.

Nasals.—The nasals are also quite large bones. They extend from the premaxillæ backward about four inches posterior to the nares, which they entirely surround and which they separate by means of thin vertical septa, which pass downward for some distance in the median plane, how far is not determined, but since one

is exposed by the breaking away of the outer bony cover for at least one and one-fourth inches they must extend somewhat further beyond.

As is the case with the premaxillæ, and indeed with all the bones of the roof of the skull adjoining the median line, the median suture remains distinct. The nasal septa are plainly separate and the suture may be readily distinguished along the whole length of the skull as far as the supraoccipital where it becomes indistinguishable.

The nasal has not a very wide lateral extent, but if the boundaries as indicated in describing the maxilla are correct, it is limited to the upper part of the skull and has nowhere a width of more than one and one-half inches, although its extreme length is probably about nine inches. It is somewhat elevated around the naris, and so raises this opening slightly, and it is excavated for nearly its entire depth opposite the anterior half of the naris, leaving this open to the side for a depth of fully one inch. In life this lateral space was doubtless covered by the integument, confining the nostril to the upper surface of the skull. Whether or not the nasal reaches the antorbital vacuity is not certainly known, but it very probably does so for a short distance, perhaps from one-half to one inch, between the lachrymal and the maxilla.

Frontal.—Behind the nasal on the roof of the skull is the frontal, a long, narrow, subrectangular bone nearly four inches in length which unites with the nasal by a strong, splintery suture. The bone extends as far as the posterior limit of the orbit, a part of whose superior margin it forms. It is ornamented with irregular, longitudinal grooves and ridges on its anterior portion and by shorter pits and rugosities in the central and posterior regions.

Prefrontal.—This is also long and narrow, but is less regular in outline than the frontal. It is limited behind by the orbit and extends forward slightly beyond the frontal, where it terminates bluntly and is inserted into a notch in the nasal.

Lachrymal.—Between the prefrontal and the maxilla lies the lachrymal, a broad, irregularly shaped bone which forms the upper part of the arch between the orbit and the antorbital vacuity. Both of these openings penetrate this bone somewhat from front and rear, so that on the line between them it is constricted to a relatively narrow isthmus. The main body of the lachrymal gives off a slender anterior

process which forms the posterior half of the upper margin of the antorbital vacuity and excludes the prefrontal from this opening.

The lachrymal enters into and forms the greater part of a depressed area which lies behind the antorbital vacuity and extends almost to the orbit, leaving only a narrow bar elevated to form the lower anterior margin of the orbit.

Parietals.—Behind the frontals the parietals form the posterior portion of the cranial roof. They unite with the frontals by transverse sutures and are here narrow, but after widening gradually for about five-eighths of an inch they suddenly broaden to twice their anterior width and so continue, until they reach the anterior extremities of the supratemporal fossæ. They form the anterior one-half of the inner boundaries of these fossæ and here meet the squamosals in sutures which slant backward for some distance and then pass transversely to the edges of the median notch, along which they slope posteriorly so that on the under surface the parietals extend backward as thin narrow plates under the squamosals to within one-half inch of the posterior margins of these bones. That part of the parietal which borders the supratemporal fossa on its inner margin is deflected steeply downward and outward, leaving a long, oblique depression of triangular cross-section, in the outer wall of which the fossa is excavated. At a point a little more than one-half the distance from their anterior to their posterior margins the parietals separate and diverge widely, leaving a broad, rather deep, triangular recess which is bounded behind the parietals by the squamosals. This notch opens very gradually during the first one-half inch of its length, and then widens much more rapidly to the posterior margin of the skull. It is floored in its anterior part by the supraoccipital, and here the parietals nearly completely arch it over from side to side.

Jugal.—Behind the lachrymal and the maxilla lies the very irregularly shaped jugal. Its suture with the quadratojugal is exposed as a long curved line sloping diagonally backward and downward from the lower posterior angle of the lateral temporal vacuity almost to the point of the jaw. The posterior part of this element thus appears as a long, slender, wing-shaped extension forming the margin of the jaw. Anteriorly the bone widens, forms the cheek between the lateral temporal fossa and the margin of the skull and curves upward

in front of the fossa to form part of its anterior margin. This wing of the jugal tapers upward until at its union with the postorbital, which passes down to complete the margin of the fossa, it forms with the postorbital a narrow bar of about one-fourth inch width separating the fossa and the orbit. The jugal also forms part of the lower boundary of the orbit and here unites with the lachrymal. Its anterior limit and its union with the maxilla cannot be determined; the probable relations have already been discussed in connection with the maxilla.

Postfrontal.—The postfrontal is a short, irregular, subquadrangular bone lying in the angle formed by the frontal and parietal, with which it unites by oblique sutures. It forms the posterior part of the upper margin of the orbit and laterally unites with the *postorbital*, a long, rather slender, quite irregular bone whose anterior extremity enters into the slender arch between the orbit and the lateral temporal fossa, and the posterior extremity into the robust bar between the supra- and lateral temporal fossæ. This latter bar is completed posteriorly by the squamosal, with which the postorbital unites by a broad, overlapping suture. It has a width of about three-fourths of one inch.

Squamosal.—The squamosal has an exceedingly irregular outline owing to its relations both with other bones and with the openings located in this part of the skull. Its anterior margin is incised by both the lateral and supra-temporal fossæ, which divide this part of the bone into three parts. The inner portion forms the proximal margin of the supra-temporal fossa along nearly one-half its length, and unites with the parietal as described in discussing that bone. The central part enters into the arch between the two fossæ, as stated above, while the outer portion extends as a long, gradually tapering wing forming the posterior margin of the lateral temporal fossa along nearly the entire length of that opening. This portion unites along its inferior edge with the quadratojugal and the quadrate in a long, oblique,. crescentic, squamous suture. The posterior part of the squamosal borders the posterior half of the large median notch, and forms the rear part of the skull for about one and one-half inches of its width and is then deflected vertically downward to outline the inner border of a small, narrow, obliquely directed notch which pene-

trates the skull margin for an inch. The quadrate also assists in bounding this notch, not only on its outer side, whose entire margin it forms, but also on its forward end and on about one-third of its inner border. Immediately above and in front of this notch the squamosal is hollowed out somewhat to form the opening of the otic capsule, which is also set into the quadrate to about an equal extent.

Quadrate.—This element, from being rather narrow above, widens considerably below and on its lower margin is thickened to form the articulation with the lower jaw. Besides being sculptured on the posterior margin for the reception of the otic capsule and the notch as described above, the quadrate also partially encloses on its anterior margin the quadrate foramen, which pierces the side of the skull slightly above the middle of the length of the quadrate, and is boundéd anteriorly by the quadrato-jugal. The quadrate extends on to the lower side of the skull for a short distance and unites with the broad posterior wing of the pterygoid and with the lateral process of the exoccipital along its anterior surface.

Quadratojugal.—The quadratojugal unites below the quadrate foramen with the quadrate in a large squamous suture which lies in the plane of the quadrato-jugal and at right angles to that of the quadrate. A buttress from the quadrate increases the sutural surface and strengthens the union. The quadratojugal is a thin flattened bone. It is almost entirely excluded from the margin of the jaw by the slender extension of the jugal. It reaches the edge just at the point of the jaw and forms about an inch of the margin in this region, although most of this distance is shared with the quadrate. Its upper anterior portion forms the lower posterior margin of the lateral temporal vacuity for about one inch, but is excluded from the margin above by the squamosal.

The posterior margin of the bone is excavated to some depth at about its middle to assist in forming the quadrate foramen, above which the bone again unites with the quadrate.

OPENINGS OF THE SKULL

Nares.—As has been said the nares are situated far backward. In fact they are more than half-way from the anterior to the posterior extremities of the skull, as the distance from the end of the snout to the

anterior point of the nares is fifteen and one-half inches, that from the posterior extremity of the nares to the rear line of the skull is twelve and five-eighths inches. The nares are about one and three-fourths inches in length with an extreme width of five-eighths inch. Behind the point of greatest width they narrow somewhat, and in front of this point they taper quite rapidly forward. In this region the outer wall is cut away, leaving the naris open laterally, as previously described in connection with the nasal. The aspect of the nares is upward in the posterior part, forward and lateral in the anterior portion where the side wall is cut away.

About midway between the frontal and the nares the nasals begin to be elevated and rise gradually to the rear point of the openings. From this point forward they begin to descend, very gently for about half the length of the nares, thence more abruptly to their presumable union with the premaxillæ, which continue the slope an inch or so farther, when it merges into the long, horizontal, upper line of the snout.

Antorbital vacuity.—A short distance behind the nares lie the antorbital vacuities, large ovoid openings with their smaller ends posterior and their long axes directed obliquely backward, upward, and inward in direct line with the axes of the orbits. The length of the vacuity is three and one-half inches and the width two and one-fourth inches. Of the elements which form the margins of this fossa the maxilla is by far the most important, as it makes up the anterior part of the upper margin (just how much is not certainly known), all the anterior border, and the lower border to within one and one-fourth inches of the rear extremity. Here it meets the lachrymal, which bone continues the rear margin and the posterior half of the upper. This leaves not more than one inch of the upper border into which the nasal enters.

The anterior wall of the vacuity is steep, as is also the posterior part of the upper margin, but between these is a narrow depression in the skull, which seems to be natural and which extends obliquely forward and inward about half-way to the nares. Behind the vacuity is a broad, rather deep depression which extends backward an inch from the rear margin and then slopes upward rather steeply toward the anterior margin of the orbit. It drops the lower anterior part

of the lachrymal, and the upper margin of the maxilla in its vicinity is also depressed to form its wall.

Orbits.—One inch behind the antorbitals are the orbits. These are considerably smaller than the antorbital vacuities, as their greatest length is two and three-eighths inches, while their width is one and five-eighths inches. The aspect is upward and outward. The outline is ovoid, with the smaller curve anterior, and the axis points slightly outward and downward. The frontal forms the upper median border, the prefrontal extends thence forward almost to the anterior limit, and the lachrymal contains the narrow curve of the extremity and extends along about one-third of the outer margin. Behind this the upper limb of the jugal enters into the border for another third of its length and meets on the narrow bar between orbit and lateral temporal fossa with the postorbital, which completes the margin to the posterior extremity. From here the postfrontal completes the circuit. The bones forming the inner border of the orbit are turned upward along their margins and form a thickened wall elevating the orbit and giving it a more outward aspect.

Lateral temporal fossa.—The upper line of the lateral temporal fossa lies about behind the middle of the orbit and the cavity extends forward and downward at an angle of about 45° with the axis of the skull to a point almost opposite the shorter axis of the orbit. It is subquadrangular in outline, but the upper posterior angle is extended into a tongue-like embayment which is excavated into the squamosal for a short distance. The length of the fossa is three inches and its width one and three-fourths inches.

The anterior and posterior walls are practically straight and nearly parallel, with a slight divergence, especially at the lower end. The lower margin is slightly concave and its general trend is about at right angles to the lateral margins.

The upper margin is formed in part by the squamosal, which extends above the vacuity as a bar about three-fourths inch wide. Anteriorly this unites with the postorbital and each makes up about one-half of the arch. The postorbital also extends around in front of the fossa and unites with the jugal to form the narrow bar separating the vacuity from the orbit. The jugal also forms the entire lower border to the point where it begins to rise to the posterior margin.

This curve is formed by the quadratojugal, and immediately above this the squamosal enters the margin and continues its outline to the upper border.

Supratemporal fossa.—Lying above the lateral temporal is the supratemporal fossa, much smaller than the lower opening and, unlike the other openings of the skull, facing inwardly, and that in a plane which has a very high inclination. In order to adapt itself to this condition the parietal is in this region deflected downward and forms the floor of the fossa with an outward slope of about 30°. The result is the irregular, suboval depression of triangular section described above.

The anterior margin of the fossa is formed by the parietal, with the exception of the outer angle. The parietal also forms a little more than one-half of the inner border, and the squamosal forms the remainder. On the outer border the squamosal forms the margin for at least two-thirds of the length of the fossa. The boundary is completed by the postorbital, which extends to the anterior margin to meet the parietal.

The fossa measures two and one-half inches in length by three-fourths inch in extreme width, in its anterior portion, though in the posterior region it narrows to a width of one-fourth inch. In shape it is a narrow, irregular ovoid, almost gourdlike in outline, as the narrow posterior part curves slightly upward in characteristic fashion. The plane in which the opening lies is not parallel with the median line, but diverges posteriorly at an angle of about 20° along the anterior two-thirds of its length; thence the divergence suddenly increases, approaching 55°.

Quadrate foramen.—One of the smallest apertures of the skull is the quadrate foramen, situated, as previously described, between the quadrate and the quadrato-jugal, about midway in the height of the former bone. It is subcircular in outline and has a diameter of about three-fourths inch. In the natural condition of the skull the opening must have faced almost directly upward.

Another opening of the skull, but one which is imperfectly closed, is the small notch in the posterior margin already mentioned. It is hollowed out of the quadrate in large part, although the squamosal forms part of its posterior margin. It lies in the upper portion of

the quadrate above and behind the quadrate foramen. It has a height of three-fourths inch, with a maximum width of five-eighths inch, at its lower, open end.

Otic capsule.—The ear opening is about the same size as the quadrate foramen and lies almost directly above it and separated from it by seven-eighths inch of bone. It is irregularly oval in outline with a height of seven-eighths inch and a width of five-eighths inch. The axes of this opening, and of the small notch which lies below and slightly behind it, lie in the same line, and the two openings are so close together that their margins are confluent.

Within the skull the ear cavity enlarges slightly and extends inward to a depth of seven-eighths of an inch. At the bottom of this subspherical cavity a smaller opening three-eighths by one-fourth inch leads into the cranium through the large cavity between the roof and the floor of the skull. The angle at which the ear opening enters the skull is about 55° from the median line of the skull, similar to that formed by the posterior end of the supratemporal vacuity.

So far as can be ascertained this is the first time this opening has been figured and described. Fraas does not show it in his illustrations of *Belodon kapffi* and *Mystriosuchus planirostris*, nor does Cope figure it in his illustrations of *Belodon buccros*. Von Meyer in his illustrations of *Belodon kapffi* shows an opening in the skull which at first sight appears to correspond with this one, but on further examination it proves to be the posttemporal fossa. Neither is the opening shown on McGregor's excellent illustrations of *Mystriosuchus planirostris* and other forms, given in his recent paper on the Phytosauria.

THE UNDER SURFACE OF THE SKULL

This surface presents, in general view, a long triangular depression which extends from the anterior portion of the snout backward as far as the basipterygoid processes of the basisphenoid. This depression is very narrow where contained by the premaxillæ, but widens gradually in the posterior part of these bones and behind them, until it attains its greatest width opposite the anterior portion of the transverse bones. It is bounded laterally by the premaxillæ and maxillæ, postero-laterally by the transverse bones and posteriorly by the short, transverse, wedge-like processes of the pterygoids and

by the basisphenoid. It is roofed by the premaxillæ, a little of the maxillæ, the palatines, pterygoids, and vomers. Three openings pierce it—the paired internal nares and the presphenoidal opening. Behind it medially lies the strong framework of the brain-case, and on either side the large depressions inclosed by the quadrates, quadrato-jugals, and jugals, and pierced by the lateral temporal fossæ and the quadrate foramina.

Where contained by the premaxillæ the trough is bounded on either side by a rounded ridge outside of which are the teeth sockets. This ridge has already been mentioned in connection with the general description of the skull.

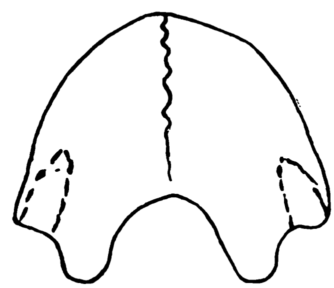


FIG. 4.—Cross-section of premaxilla eight inches from extremity of snout.

The end of the snout bears two large teeth on each bone, then a smaller one, separated from them by about one-fourth of an inch. Between this tooth and its nearest neighbor to the rear is a space of three-fourths inch. The other teeth are closely set—not over one-eighth inch apart in most cases—and increase in size gradually from front to rear. The total number on each side is thirty-six, of which twenty are on the premaxilla, the remainder on the maxilla. With one exception all the teeth have been lost and the sockets filled with the sandstone matrix. The single tooth which remains is the second from the rear. It has been somewhat flattened by crushing, but its average cross-section is seven-sixteenths inch. It contains within its cavity a younger small tooth. The teeth of this specimen were apparently all of circular cross-section, resembling those of Fraas's *Mystriosuchus* rather than those of von Meyer's *Belodon*. They must have pointed obliquely outward.

The premaxilla extends somewhat farther back on the under surface than above, as in the former region it has a length of eighteen and one-half inches. Along the last six inches of this distance it is excluded from the margin of the jaw by the maxilla.

Maxilla.—On its lower side the maxilla presents a flat surface from which spring the rather large teeth of this portion of the jaw.

At its anterior extremity this surface is not over three-eighths inch wide, but at its widest extension, at the thirty-fourth tooth, it is one inch across. Back of the last tooth the bone narrows abruptly. About opposite the posterior end of the premaxilla the dentiferous surface of the maxilla begins to be depressed below the palate and this depression increases until opposite the rear teeth it is about one inch. Just behind this region a rounded buttress-like process passes down the inner surface of the maxilla nearly to the edge of the jaw. It may be that the jugal forms the upper part of this buttress, but this is not known. The process is pierced by a small foramen which extends nearly parallel to and about one-half inch above the edge of the jaw. The purpose served by this foramen is uncertain.

Between the twenty-eighth and thirty-third teeth the maxilla bears an obtusely triangular extension which lies perhaps three-fourths inch above the dentiferous margin and enters into the lateral portion of the bony palate.

Palatine.—The anterior limit of this element is not positively known, but its relations with the premaxillæ are believed to be about as indicated in the figure. Posteriorly it widens as the maxilla narrows and reaches its extreme width—one and one-half inch—opposite the posterior limit of the internal nares. Behind this point it tapers gradually, chiefly by being cut away on the outer edge, and leaves the maxilla more and more as it passes backward. Its extreme length is probably six and one-half inches. It is united with the maxilla along the outer edge back to the line of its greatest width, but from here to the posterior end the two are separated by the transverse (ectopterygoid) with which the palatine unites by a roundly serrate suture. The two bones separate slightly about midway along the suture, and leave the narrow palatine vacuity between them. Along the inner margin the palatine unites with the pterygoid as far forward as the internal naris, whose entire outer margin it is believed to form. It probably overlaps the maxilla somewhat in its anterior portion as is apparently true of the European belodonts.

The palatines lie at a somewhat lower level than the pterygoids and so leave between them a cavity in the palate in which lie the pterygoids and vomers. The inner edges of the palatines are turned vertically upward to unite with the pterygoids. It is probably the

ridge thus formed of which Cope speaks in his description of *Belodon buceros* when he says that the palate has a strong ridge on each side so as to be grooved (*Proc. Am. Phil. Soc.*, Vol. XXIV, 1887, p. 217).

Transverse.—This is an irregular bone the posterior part of which originally was directed vertically downward, while the anterior part is turned over at right angles and lies horizontally between the maxilla and palatine. The bone has been somewhat displaced from its original position by pressure. Across its widest portion it measures one and three-eighths inches, and its thickness in this same region is five-eighths inch. Farther forward, where the bone is turned over, its breadth is seven-eighths inch and diminishes anteriorly, while its thickness is seven thirty-seconds to nine thirty-seconds of an inch. The anterior part has been broken away, but the full length must have been three and three-eighths inches. Its anterior part united along the outer edge with the maxilla, along the inner with the palatine. The posterior vertical portion united along its whole outer face for the rear one and one-fourth inches with an extension of the pterygoid. The transverse probably touched the above-mentioned buttress of the maxilla.

Apparently the separate existence of this bone was not recognized by von Meyer in describing his specimens of Belodon. In discussing *B. kapffi* (*Paleontographica*, Vol. X, p. 234) he says that the anterior end of the pterygoid becomes pointed and extends as far forward as the third alveola of the maxilla with which bone it unites outwardly, while inwardly the union is with a bone which may be the palatine, and with which it bounds a sharp oval opening 26^{mm} long and $6\frac{1}{2}^{mm}$ broad (the palatine vacuity). He also states that this bone, together with the jugal, which it touches, forms the anterior angle of the temporal fossa. These statements apply exactly to the transverse, hence it is certain that von Meyer did not observe the suture between the transverse and the pterygoid. Of what he considered the large area of the palate to consist is not clear, but probably he thought that the palatines extended to the median line. This has been shown not to be the case, however, since they are widely separated by the pterygoids and vomers. Cope does not mention the transverse in his description of *Belodon buceros* (*Proc. Am. Phil. Soc.*, Vol. XXIV, 1887, p. 217), although he recognizes the presence

of the pterygoids in the roof of the palate, which von Meyer did not do. Cope (*Syl. Lect. Vert.*, p. 72) figures the transverse, but his figures do not show any sutures.

E. Koken discusses ***Belodon*** briefly in his paper on *Thoracosaurus macrorhynchus* in *Zeitschr. d. Deutsch. geol. Gesellschaft*, Jahrg. 1885, pp. 763–65. He recognizes the separate existence of the transverse in the following statement, which he makes under heading 4:

> Zusammen mit den Palatinen und Transversen umschliessen sie [Pterygoids] schmale Gaumenlöcher, von deren Umgrenzung der Oberkiefer ausgeschlossen ist und die denen der Crocodiliden gar nicht gleichen, sondern ganz auf Lacertilier herauskommen. Auch das starke Vorspringen der Ossa transversa ist Eidechsencharacter.

The transverse is recognized as a separate bone by McGregor in his paper already quoted, where he describes and figures the bone. His illustrations give an excellent idea of the form of the transverse and of its sutural relations. McGregor, however, omitted mention of Koken's article cited above, and does not include it in his bibliography. But since the latter's paper appeared many years previous to that of McGregor his description of course has priority as being, so far as is known to the writer, the first recognition of the element under discussion.

Pterygoid.—The pterygoid may be said to consist of three parts: first, the broad, thin, flat bone which forms a considerable part of the palate from the internal naris back almost to the rear end of the transverse; second, the short, almost vertical lateral extension already mentioned as united to the transverse; and third, a long posterior wing which unites with the quadrate. The entire length of the bone is seven and one-half inches and the greatest width, that across the lateral wing, must be about three and one-fourth inches. The anterior extremity forms the outer half of the posterior border of the internal naris and extends for perhaps one-half inch along the outer margin. The bone widens gradually backward for three inches and then gives off the lateral extension. The anterior portion is terminated behind very abruptly by a sharp-edged, vertical, transverse process which marks the beginning of the posterior wing. At first the lateral wing is only five-eighths inch wide, but it broadens

distally so that that part which unites with the transverse has a width of one inch. It bears on its outer free surface a rounded vertical ridge which adds considerable strength to the bone. It is on the inner face of this extension that the transverse is attached.

The posterior wing begins with the vertical process referred to, which has a height of seven-eighths inch and an extent across the palate of one and one-eighth inches, and merges with the lateral wing. The posterior wing forms a broad, nearly vertical plate. Its upper edge comes in contact with the lower part of the cranium. The lower edge is thickened and presents a broad surface very much as this element does in *Amblyrhynchus*. The quadrate unites with the pterygoid along the entire posterior border of the latter bone. This portion of the pterygoid, as indeed the entire bone, presents strong lacertilian affinities, and resembles the bone as found in lizards and mosasaurs much more than that in crocodiles, where the quadrate occupies the space here taken by the pterygoid.

The vertical transverse processes may be taken as marking the posterior boundary of the palate, although between and partly behind them is an opening into the interior of the skull, which may belong to the palatal region.

Koken, in his paper to which reference has already been made, states that the pterygoids *scarcely* come in contact. Whether by this he means that they *do* meet is not clear, but they certainly do not do so in the specimen studied. Here they are separated by the *vomers*, which extend from the posterior wings of the pterygoids forward to the nares and between these as much-narrowed bones. It is probable that they again widen in front of the nostrils and here meet the palatines laterally and the premaxillæ anteriorly, a short distance, perhaps one-half inch, in front of the end of the nares. The maximum width of the vomers is five-eighths inch.

Cranium.—The brain-case is very small, measuring not over two and one-half inches from the opening of the foramen magnum to the beginning of the olfactory canal, and about one and one-fourth inches in transverse diameter, external dimensions. The roof is formed by the extreme posterior portion of the frontals, the parietals, and the supraoccipital. The lateral walls are composed of the alisphenoids, the proötics, the inferior processes of the parietals, and the

exoccipitals. The opisthotics may exist coössified with the exoccipitals as in other reptiles, but this is not determinable. The bones forming the floor are the alisphenoids, which are united in their anterior parts only, the basisphenoid and the basioccipital. A small spatulate bone which is attached to the lower margin of the posterior por-

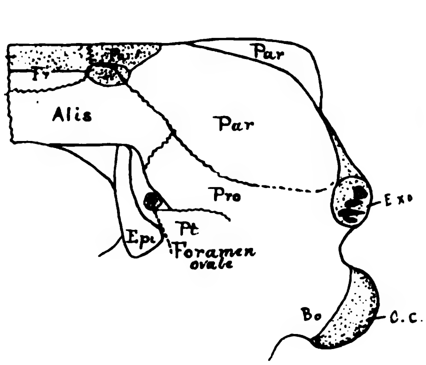


FIG. 5.—Cranine bones from side.

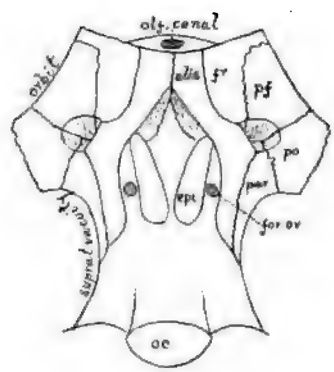


FIG. 6.—Bones of brain case.

tion of the alisphenoid and thence extends downward and slightly posteriorly to unite with the pterygoid, is here considered as the *epipterygoid*. In shape and mode of attachment it occupies a position intermediate between the long slender epipterygoid of the lizards and the short, solidly attached (so-called) epipterygoid of the modern crocodiles. Instead of there being only a small foramen between the epipterygoid and the cranium, as in the crocodile, a large space exists beneath the epipterygoid, more like the condition in *Amblyrhynchus*, for example. It is probable that in life this space

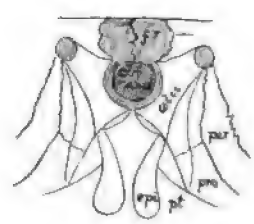


FIG. 7.—Cross-section through rhinencephalic canal.

was still larger than at present, and that it has been reduced by crushing. Just in front of the epipterygoid is the opening for the III, oculo-motor, and VI, abducens, nerves, and behind it is the fenestra ovale. The foramen magnum is oval in outline and quite large. Its floor is formed by the basioccipital, its walls by the exoccipitals, and the roof by the supraoccipital. The brain-case is continued

anteriorly by the olfactory duct, formed by the frontals above and the alisphenoids below. This duct has a diameter of three-eighths inch. Its length is unknown, as the anterior part is concealed in the matrix. It presents a marked contrast to the condition in modern crocodiles, in which its place is taken by a shallow trench and the alisphenoids are not continued forward and do not meet in the middle line. No other openings from the brain-case can be made out because of the presence of matrix where they might be expected to occur.

Of the lower elements of the cranium the most anterior is the *alisphenoid*. This bone is of irregular outline, thin and curved in its front portion to encircle the olfactory lobes. Behind it sends outward and upward a strong process which rests in a depression in the under surface of the postfrontal and postorbital. To the rear the alisphenoid unites with the downward extension of the parietal above and with the proötic below, by oblique sutures. The lower margins of the alisphenoids gape in the posterior region and it is here that the neural foramina occur and that the epipterygoid is attached. As already indicated the anterior portion is concealed.

Only the anterior part of the proötic is exposed and this is seen to be united with the parietal above and the alisphenoid in front. The lower anterior margin is free and borders the foramen ovale. Below this it unites with the pterygoid for a short distance and its lower posterior border meets the exoccipital.

It seems probable that the *basisphenoid* occupies a relation similar to that in the crocodile, that its upper portion is covered by the pterygoid and that the alisphenoid passes downward on the inner side of the pterygoid and epipterygoid to unite with the basisphenoid.

In shape the basisphenoid is very irregular. Where it meets the basioccipital the two bones form a strong transverse ridge, of which however the basioccipital forms only a small part. Anteriorly it sends off the strong downward and forward-reaching basipterygoid processes. Between and above these a vertical rostral plate forms an incomplete septum called by Dr. W. J. Holland the presphenoid in *Diplodocus*. Posteriorly and superiorly the basisphenoid probably unites with the posterior process of the pterygoid and with the exoccipital.

The *basioccipital* forms the chief part of the short stout occipital

condyle. The relations with the basisphenoid have already been mentioned. It is evident from the oblique position of the condyle that the animal held its head at an obtuse angle with the body, very much, probably, as Dr. Holland has figured the dinosaur *Diplodocus carnegiei* in Fig. 1 of his paper on the osteology of *Diplodocus*.

The *exoccipitals* form a little of the condyle, most of the floor and all of the side walls of the foramen magnum, but unlike the condition in the crocodiles and dinosaurs they are widely separated above as in *Amblyrhynchus* and the mosasaurs. Outwardly they have a subcircular cross-section and distally give rise to the long, flattened paroccipital processes which buttress the under surface of the skull and along which the inferior part of the quadrate is attached for some distance. The inferior processes of the parietals probably touch the exoccipitals along their upper edges for some distance.

The *supraoccipital* is roughly triangular as seen from above, with the apex anterior, and all three sides slightly concave. Its upper surface is also quite concave and slopes backward rather steeply. It forms a floor for the anterior part of the deep median sinus previously mentioned. The bone has a width across its base of two and one-fourth inches and its length along the median line is about one and one-half inches. It unites with the exoccipitals by horizontal sutures and thickens along its margins to unite with the parietals in strong vertical sutures.

OPENINGS ON THE UNDER SURFACE OF THE SKULL

Internal nares.—These are the most anterior openings on the palatal surface. Unfortunately they have been almost obliterated in the crushing which the skull has undergone and only the posterior portion of one naris is now visible. This has a width of about five-eighths inch. Its probable anterior dimensions are indicated in the figure. The length cannot be greater than two and one-fourth inches and may be somewhat less than this. The nares are separated by the vomers, which also form part of their posterior borders. These are continued by the pterygoids, and the palatines enclose the openings on the sides. The vomers are thought to form the anterior borders. The internal nares are not, like those of *Belodon*, placed beneath the external, but lie entirely behind them. The anterior

limits of the inferior openings must lie at least one and one-half inches posterior to the rear border of the superior nares.

Palatine foramina.—The small palatine vacuities follow in order. They are not over one inch in length by one-fourth inch in width, and as has been stated are enclosed by the palatines and transverse bones.

In the median line there exists a cordiform opening with a length of one and three-eighths inches and a maximum width of one and one-eighth inches. The apex of this opening is directed anteriorly and separates the vomers for a short distance. Behind the vomers the pterygoids bound the opening. The basipterygoid processes of the basisphenoid lie below and behind the opening; whether they form part of its margin is not known. The vertical anterior plate of the basisphenoid perhaps partly divided this opening in life, but if so it has since been forced to one side.

Posttemperal fossa.—Above the proximal portion of the exoccipital lies the posttemporal opening. As seen from behind this is a small opening nearly an inch long and one-fourth inch high. Immediadiately above the exoccipital the fossa is roofed by the squamosal; in front of the exoccipital it pierces the roof of the mouth and communicates with the great cavity of the skull. On the outer side the border is formed by the quadrate behind and the pterygoid in front. The anterior border is probably formed by the pterygoid and the posterior wing of the parietal, which also forms the inner border.

Infratemporal fossa.—This forms a large irregular opening on the under surface, bounded proximally by the pterygoid and palatine, distally by the quadrate, quadratojugal, jugal, and maxilla.

THE LOWER JAW

Only the posterior part of one mandible is present, but this shows strong belodont affinities and differs markedly from that of the crocodiles. In general outline it resembles the mandible of *Belodon plieningeri* figured by von Meyer (*Paleontographica*, Vol. XIV, Pl. 23). The crest of the surangular is much higher than in the Crocodilia and the portion behind the articular surface is much shorter than in that order. It probably does not extend more than an inch behind the

articulation. The external fenestra is quite elongate though its exact limits are unknown. The probable outlines are indicated in the figure. Only a portion of the posterior margin of the internal fenestra remains, together with the lower margin of the small internal mandibular foramen. None of the symphysis is present.

Owing to the condition of the mandible but few sutures can be made out. However, that between the *articular* and the surangular on the broad, vertical posterior face of the jaw is clearly distinguishable. The outlines of the posterior portion of the angular are also quite distinct. The articular forms the inner two-thirds of the articulation with the quadrate, while the outer third is formed by the surangular. The articular also forms nearly all of the transverse vertical area on the posterior extremity previously mentioned. At the inner border of this area is given off a strong, subrectangular process which is widely separated from the inner face of the jaw and extends nearly parallel with it. The main part of the articular extends forward for some distance, forming the lower margin of the internal fenestra. It may extend as far forward as the internal mandibular foramen, as stated by McGregor to be true in *Phytosaurus*, but this cannot be determined.

Angular.—This element is exposed for a width of about an inch on both sides of the ramus, whose lower margin it forms. It probably forms the posterior angle of the jaw and constitutes its margin for a considerable distance under the fenestræ.

Surangular.—The surangular forms nearly all the outer face of the mandible in its posterior part and makes up the high crest of the jaw, besides entering into the articular surface which meets the quadrate. It is ornamented a little above the middle of its height by a strong, nearly horizontal ridge, slightly concave upward, which starts below the articulation, where it has a width of nearly one-half inch. It narrows anteriorly and becomes quite sharp before it disappears.

The limits of the *splenial* on the inner surface and those of the *dentary* on the outer cannot be determined. Probably they correspond with those of *Belodon* and *Mystriosuchus*.

The outer surface of the mandible is quite rugose in its hinder part and somewhat so farther forward. The rugosities consist

chiefly of small, rounded eminences, with some ridges. The inner surface is rather smooth.

With regard to the nomenclature of the mandible it may be stated that the one generally accepted is here used. As is well known Baur (*Anat. Anz.*, Vol. XI, 1896) attempted to modify the classification of the bones by applying the name of angular to a long splint-like element in front of the articular instead of to the bone previously designated by this name. This necessitated a shifting of names and Baur called the angular "splenial" and the splenial "presplenial." Baur's primary mistake lay in his accepting the turtle as the basis of nomenclature while the original nomenclature was based on the crocodile.

Kingsley has since (*Am. Nat.*, 1905, pp. 59 ff.) corroborated Baur's observations as to the origin of these bones and, taking the crocodile as the standard, has retained the names of the bones as originally given by Cuvier and Owen. Thus he designates the so-called splenial of the turtle of authors, the splenial of Baur, the "dermarticular."

Williston had, however, previously discussed this bone from the plesiosaurs ("North Am. Ples.," *Field Col. Mus.*, *Geol. Ser.*, Vol. II, No. 1, 1903, pp. 29–32) and had given it the name of prearticular. This name should then have priority over that of Kingsley. The prearticular is apparently absent from the crocodiles, while it is a distinct bone in plesiosaurs, dinosaurs, turtles, and some other early reptiles.

THE ILIUM

This bone presents features which distinguish it quite markedly from that of *Rhytidodon* as figured by McGregor. The acetabulum is quite broad and must have been quite largely contained by the ilium. Above the acetabulum is a strong process which rises fully two inches above the depth of the cavity. It is of triangular cross-section and is formed by the junction of three ridges, two of which bound the acetabulum and form its upper walls, while the third extends obliquely forward toward the upper anterior corner of the bone. This ridge is very strong where it rises up to aid in forming the process, but it thins distally and does not quite reach the anterior extremity. The upper anterior process has a rounded outline and, unlike *Rhytidodon*, its

upper border is quite elevated and is limited by a broad shallow sinus from the remainder of the upper margin of the bone. The lower anterior process is much shorter and blunter than is that of *Rhytidodon*. Instead of being drawn out to a point it ends in an enlarged, oblique, vertical face of triangular shape. The lower posterior border is rounded and presents a large, roughened surface for the attachment of muscles. The postacetabular process has been broken off but was doubtless similar to that in *Rhytidodon*. The upper border was doubtless somewhat convex, although not so much so as in *Rhytidodon*,

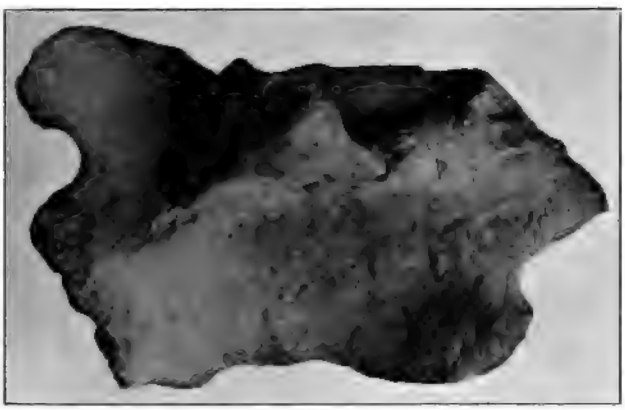


FIG. 8.—Ilium of *Paleorhinus bransoni* Williston.

but as already stated its convexity is interrupted by a broad sinus, giving the anterior part a decidedly concave outline.

On the inner surface the bone is relatively smooth except for the long, shallow trench along its upper part for the reception of the sacrum. This trench is outlined along much of its length by slightly elevated and angular ridges. Below this trench there is also at the anterior extremity of the bone a shallow, ill-defined depression.

The new features which the present study has disclosed may be here summarized. The presence of the otic capsule and its relations and dimensions have been determined. The sutural relations of the palatine, pterygoid, and vomer have been more clearly delineated, and the unsuspected posterior extension of the latter element as far as the presphenoidal vacuity demonstrated. It is believed also that the

elements of the brain-case have been more completely identified than has been possible previously and their relations more clearly made out. The enclosure of the olfactory canal by the alisphenoids, the presence and character of the epipterygoid, here so considered, and the relations of the roof bones and the cranial elements are points which so far as known have not heretofore been noted. It is hoped that these determinations have been made with sufficient accuracy to serve for purposes of future comparison.

Another feature distinctive of this genus, although one mentioned by Dr. Williston in his paper previously noted, is the anterior position of the external nares. The position of the internal nares behind the external also seems to be a new character.

RELATIONSHIPS OF PALEORHINUS

In comparing the specimen under discussion with the belodonts we may adopt here McGregor's division of the group into *Phytosaurus* and *Mystriosuchus*. If we include under the former genus the European forms with high rostrum—*Ph. kapffi* and *plieningeri*—and Cope's species, *Ph. buceros*, these may be dismissed at once, since the differences between this group and *Paleorhinus* are great enough to be considered generic. Fraas in 1896 separated *Belodon planirostris* from the genus and founded a new one, *Mystriosuchus*, for it, because of the great differences in the shape of the snout. The skull of *Paleorhinus* presents similar differences, hence its distinctiveness may be taken for granted. Of Cope's species, *Belodon scolopax*, little can be said since that was based on the anterior portion of a rostrum which, Cope states, is "shorter but much more slender than that in *B. plieningeri*." This gives but slight basis for comparison.

Between *Mystriosuchus* and *Paleorhinus*, however, there appears at first glance to be an intimate relationship. But, upon closer examination, certain features are seen to be widely divergent in the two specimens. In the first place, that part of the skull of *Paleorhinus* which lies in front of the anterior point of the nares is one inch longer than the portion behind this point. In the case of *Mystriosuchus*, on the other hand, the distance from the tip of the snout to the anterior point of the nares is five-sevenths of the entire length of the skull.

Furthermore, the proportions of the skull are quite different. The following table of dimensions will serve to make this clear:

	Mystriosuchus planirostris		*Paleorhinus bransoni*	
Length of skull	33.375	inches	30.500	inches
Width of skull across quadrates	7.875	"	9.750	"
Width of skull opposite middle of orbits	6.625	"	7.250	"
Width opposite anterior extremity of external nares	3.000	"	3.000	"
Length from rear of skull to quadrate	1.500	"	0.300	"
Length from rear of skull to lateral temporal fossa	2.875	"	2.375	"
Length from rear of skull to supra-temporal fossa, anterior extremity	2.875	"	3.700	"
Length from rear of skull to supra-occipital	1.375	"	2.300	"
Length from rear of skull to rear point of orbit	4.400	"	5.000	"
Length from rear of skull to rear point of pre-orbital vacuity	6.750	"	8.500	"
Length from rear of skull to rear point of nares	8.000	"	12.500	"
Length from rear of skull to anterior point of nares	9.500	"	14.625	"
Length from rear of skull to rear point of internal nares	8.000	"	9.000	"
Length of premaxilla	23.250	"	14.750	"
Length of maxilla	7.500	"	12.500	" (?)
Length of nasals	4.875	"	9.000	" (?)
Width of nasals	1.375	"	1.000	"
Length of frontals	2.000	"	4.000	"
Width of frontals	.875	"	1.000	"
Number of teeth on upper jaw	94		72	

There are several other differences, among which may be noted the following: In *Mystriosuchus* the parietals extend backward between the supratemporal openings at the level of the top of the skull for a little less than one inch, while in *Paleorhinus* they extend in this direction two and one-fourth inches, are widely separated, as already described, and meet the squamosals posteriorly to enclose the supratemporals at the upper level of the skull. In *Mystriosuchus* this "parietosquamosal arcade," to use McGregor's term, is considerably depressed and forms a thin plate lying on the paroccipitals. This gives the supratemporal openings and the large median notch quite a different appearance in the two specimens. Several of the openings in the skull are of different shapes in the two individuals, and the

nares particularly occupy very different positions. In the European form their anterior limits lie behind those of the preorbitals, while in *Paleorhinus* the whole of the nares lies considerably in advance of the preorbitals.

The paroccipital processes are much wider in *Mystriosuchus* and cover the parietals. The posterior wings of the pterygoids are, however, much smaller and shorter and leave a large opening which in *Paleorhinus* is filled by the quadrate and pterygoid.

Some of the distinctions mentioned above as well as those indicated in the table of dimensions might be considered as being merely specific, but some are undoubtedly of generic rank. Such are the differences in dentition and relative major dimensions of the skull, in location of the nares, in the position of the parieto-squamosal arcade, and its relations to the supratemporal fossa. These divergences would seem to be amply sufficient to warrant the separation of the individuals into different genera, as has been done.

It is impossible to make a close comparison of this specimen with Lucas' genus *Heterodontosuchus*. This latter was founded on the imperfect anterior portion of a lower mandible, while as before stated the only portion of the mandible of *Paleorhinus* which is available is the posterior part, well behind the symphysis. If one may judge from the upper jaw of *Paleorhinus* there must be some difference in the teeth of the two specimens, since Lucas stated that in *Heterodontosuchus* these are separated only by an extremely thin film of bone, while in *Paleorhinus* they are from one-eighth to one-fourth inch apart. There is evidence also that this is true in the lower jaw.

There is no indication of the "deep narrow groove" which Lucas speaks of as extending "along the side of the jaw." Neither do the teeth seem to have been compressed antero-posteriorly as in Lucas' genus. On the contrary the sockets are quite circular.

On the other hand there are some features in which the two specimens show a close similarity. In both specimens the teeth are set very obliquely in a broad, shallow groove, and the two anterior ones, together with the extremity of the jaw., are enlarged. (In all other forms where known the end of the mandible is enlarged and presumably is so in *Paleorhinus*. The enlargement of the upper jaw is very noticeable.)

It scarcely seems wise under the circumstances to make any positive statement regarding the generic identity or separateness of these two specimens without comparison of all the material available, and this has not been possible. There are other nearly perfect skulls in the collection from the Popo Agie beds quite different from the present one which have not yet been studied. Dr. Williston is doubtful as to the distinction, but inclines toward the belief that they belong to the same genus. See his paper on this specimen previously quoted.

It is chiefly because of the marked differences between the ilia of *Rhytidodon carolinensis* as figured by McGregor and of the specimen in hand, differences which are believed to be generic in value, that the specimen is considered as of another genus. These differences may be briefly summarized here. They are: the absence of the transverse ridge from the outer face of the ilium of *Rhytidodon* and its presence in that of *Paleorhinus;* the angularity of the processes in *Rhytidodon* contrasted with their roundness and broadness in *Paleorhinus;* the convex upper edge of the bone in *Rhytidodon* and its general concavity in *Paleorhinus* and the greater size and strength of the central process in *Paleorhinus*.

A comparison of the skulls of the two genera is somewhat difficult owing to the incomplete condition of the skulls of *Rhytidodon*. The distinction which impresses itself most strongly upon the attention is that between the proportions of the skulls. McGregor states (p. 59) that the prenarial portion of the skull of *Rhytidodon* must be two-thirds the entire length. In *Paleorhinus*, on the other hand, the pre- and postnarial portions are nearly equal—the prenarial portion is one inch the longer.

Another distinction between the two genera is the long backward projection of the squamosal region over the quadrates in *Rhytidodon*, while in *Paleorhinus* the quadrates and bones associated with them extend almost as far backward as does the upper surface of the skull.

Further, in *Rhytidodon* the external nares are situated over the internal and lie opposite and above the middle of the antorbital vacuities. In *Paleorhinus*, however, the external nares lie far in front of the internal openings, which are situated opposite the middle of the antorbital vacuities. The external nares thus occupy a position well in advance of the antorbital vacuities. This difference is due to the

difference in the relative position of the external nares in the two genera, since the other openings occupy similar positions in both.

There are also some minor differences in the shapes of the various openings of the skull.

The thanks of the writer are due to Dr. S. W. Williston, whose kind personal supervision and interest have made this work possible. Dr. Williston has not only given the study his attention during its prosecution and the benefit of his intimate knowledge of reptilian types, but he has also criticized the completed paper. The writer's thanks are also due him for permission to make use of the material upon which the paper is based.

BIBLIOGRAPHY

Baur, G. "Ueber die Morphologie des Unterkiefers der Reptilien," *Anatom. Anzeiger*, Vol. XI, 1895, pp. 410–15. Discusses classification of bones of mandible.

Cope, E. D. "A Contribution to the History of the Vertebrata of the Trias of North America," *Proceedings of the American Philosophical Society*, Vol. XXIV, 1887, pp. 217 ff. Describes *Belodon buceros* and *B. scolopax*.

———. *Syllabus of Lectures on the Vertebrata*, 1898, p. 72, Fig. 24. Gives illustration of *Belodon buceros*.

Emmons, E. *Manual of Geology*, 2d ed., 1860, p. 175. Gives illustration of *Rhytidodon carolinensis*.

Fraas, E. *Die Schwabischen Trias-Saurier*, pp. 15–17, Plate V. Gives illustration and brief descriptions of *Mystriosuchus planirostris*, etc.

Holland, W. J. "The Osteology of Diplodocus Marsh," *Memoirs of the Carnegie Museum*, Vol. II, No. 6, 1906. Describes *Diplodocus carnegiei*.

Kingsley, J. S. *American Naturalist*, 1905, pp. 59 ff. Discusses bones of mandible.

Koken, E. "*Thoracosaurus macrorhynchus* Bl., aus der Tuffkreide von Maastricht," *Zeitschr. d. deutsch. geol. Gesellsch.*, Vol. XI, 1888, pp. 763–65. Discusses *Belodon* in connection with other genera.

Lucas, F. A. "*Heterodontosuchus ganei*," *American Journal of Science*, 4th Series, Vol. VI, 1898, p. 399. Describes this species.

Marsh, O. C. "*Rhytidodon rostratus*," *American Journal of Science*, 4th Series, Vol. II, 1896, p. 61. Illustration only.

McGregor, J. H. "The Phytosauria, with Especial Reference to *Mystriosuchus* and *Rhytidodon*," *Memoirs of the American Museum of Natural History*, Vol. IX, Pt. II, 1906, Plates VI–XI, pp. 30–100.

Von Meyer, H. "Reptilien aus dem Stubensandstein des obern Keupers," *Paleontographica*, Vol. VII, 1861, Plates 38–47; Vol. X, 1863, p. 234, Plates

38–40; Vol. XIV, 1865, Plates 23–29. Give description and figures of *Belodon kapffi*, *plieningeri*, etc.

WILLISTON, S. W. "North American Plesiosaurs," *Field Columbian Museum Publications*, Geological Series, Vol. II, No. 1, 1903, pp. 29–32. Discusses classification of elements of mandible.

——. "Notice of Some New Reptiles from the Upper Trias of Wyoming," *Journal of Geology*, Vol. XII, 1904, p. 696. Describes briefly *Paleorhinus bransoni* and mentions other genera. Compares with *Heterodontosuchus Belodon*, etc.

ABBREVIATIONS USED IN FIGURES

Alis.,	alisphenoid.
Ang.,	angular.
Ao.,	antorbital vacuity.
Bo.,	basioccipital.
Bp.,	basipterygoid, processes of
Bs.,	basisphenoid.
D.,	dentary.
Ect.,	ectopterygoid.
E. M. F.,	external mandibular fenestra
E. N.,	external nares.
Epi.,	epipterygoid.
Exo.,	exoccipital.
Fr.,	frontal.
I. T.,	infratemporal vacuity.
J.,	jugal.
L.,	lachrymal.
L T.,	lateral temporal vacuity.
M.,	maxilla.
N.,	nasal.
Na.,	internal nares.
O.,	orbit.
O C.,	occipital condyle.
Ot.,	otic capsule.
P.,	palatine vacuity.
Pal.,	palatine.
Par.,	parietal.
Pf.,	postfrontal.
Pm.,	premaxilla.
PO.,	antorbital vacuity.
Po.,	postorbital.
Prf., pf.,	prefrontal.
Pro.,	Proötic.
PS.,	presphenoidal vacuity.
PT.,	posttemporal vacuity.
Pt.,	pterygoid.
Q.,	quadrate.
Q F.,	quadrate foramen.
Qj.,	quadratojugal.
S.,	supraoccipital.
Sur.,	surangular.
Sq.,	squamosal.
ST.,	supratemporal vacuity.
V.,	vomer.
III, V, VI,	openings of III, V, and VI nerves.

THE CRYSTALLINE ROCKS OF THE OAK HILL AREA NEAR SAN JOSÉ, CALIFORNIA

E. P. CAREY AND W. J. MILLER

CONTENTS

INTRODUCTION

The Oak Hill area is situated about four miles south of the city of San José, in the Santa Clara Valley, California. On the north of

this area is a quarry from which the city of San José obtained road material for a number of years. The road material consisted largely of diorite intruded into partially serpentinized peridotites and pyroxenites, with which they are very intimately associated.

The area mapped and studied in detail comprises nearly three square miles, namely the group of hills south of the Oak Hill Cemetery and west of the Monterey Road. This group of hills rising out of the Santa Clara Valley will be designated in this paper as the Oak Hill area, while the term "Quarry Hill" will be applied to the hill in which the quarry is situated.[1] The prevailing rock of the region is serpentine, which shows unmistakably its origin from peridotite. The transitions have been most carefully studied in and near the quarry. Not less interesting, however, are the pyroxenite and gabbro occurrences which are intimately associated, the pyroxenite showing every step in the transition into serpentine, on the one hand, and apparently into the different types of gabbro, on the other. Several diorite dikes occur cutting through the more basic rocks, and glaucophane schist has been found in a number of excellent exposures.

The region is further remarkable for the extent and variety of intrusives of more acid rocks, gabbroid and dioritic in character.

Sandstones and radiolarian jaspers make up a small part of the area and are the only rocks of sedimentary origin.

TOPOGRAPHY

The Oak Hill area comprises a group of well-rounded crests, part of an old erosion plain rising out of more recent valley alluvium which surrounds the hills on all sides. These hills really form an integral part of the Mount Hamilton Range, and are practically connected with this range by a low line of peridotite-serpentine hills, sometimes known as the Los Lagrimas Hills, which outcrop to the southeast of the Monterey Road.

Of the nine fairly well-defined crests of the area, the highest is 438.5 feet above the level of the valley. The trend of the crests is approximately northwest and southeast, which corresponds to the general strike of the Coast Ranges in this region.

[1] Work on the rocks of the Oak Hill area was carried on during the two years 1901 and 1902. The petrographic investigations were carried on at Stanford University under the direction of Dr. J. P. Smith.

The surface of the serpentinized area is hummocky and often almost destitute of soil, which character aids in determining the areal extent of the serpentine.

THE DIORITES

Occurrence and relations.—The Diorite occurs in dikes intrusive into the older pyroxenite—peridotite rocks and gabbros. The best exposure is to be found in the quarry. The dikes here constitute

FIG. 1.—North face of Quarry Hill, showing diorite dikes in pyroxenite, gabbro, and serpentine.

two sets: an older set of five nearly vertical dikes, averaging about three and a half feet in width and parallel with each other, intersected by another set of parallel dikes, averaging about four and a half feet in width and dipping toward the northwest.

The relations of these two intersecting sets of dikes are now, since the field-work was done, rather obscure, on account of a talus that is beginning to cover up some of the intersections; but some intersections are still apparent, as is evident from the photograph, and the relative age was plainly evident when the work of quarrying the diorite was in progress.

Both sets of dikes have been faulted after the intrusion, the fault zones being common to both sets of dikes. Three of these fault zones may be seen in the quarry in addition to minor displacements; but the displacement in no case exceeds a few feet. Pyroxenite, gabbro, and serpentine fill the space between the dikes in the quarry. In a cut near the east side of Quarry Hill a large diorite dike in pyroxenite shows spheroidal weathering, where the soft outer layers, which may

FIG. 2.—Banded structure in olivine gabbro—Quarry Hill—common also to pyroxenite and norite.

be easily removed, grade into extremely hard spherical cores. Other fine-grained dioritic dikes may be seen intruded into norite in an open cut on the north side of the top of Quarry Hill. Other scattered outcrops of diorite were found on Quarry Hill and over the north part of Oak Hill area, but no exposures have been observed to the south of the area nor in the Los Lagrimas Hills to the southeast.

Petrographic characters.—The color of the hand specimen varies from a light to a dark gray, while the texture varies from very fine to rather coarse-grained, so that the commonest minerals, plagioclase and hornblende, may easily be seen with the naked eye. One of

the most striking features of the coarser-grained specimens is the prominence of the hornblende crystals which make up one half of the rock. Because of slower cooling, the inner portions of the large dikes are more coarsely crystalline than the outer portions, while the narrow dikes and numerous branching tongues are fine-grained.

Upward of twenty thin sections were examined, and the chief constituents were found to be: plagioclase, hornblende, augite, biotite, and iron-oxide. Plagioclase, chiefly oligoclase and andesine, is, in all cases, the most abundant mineral. It usually occurs in large idiomorphic crystals, frequently twinned according to the albite law. The crystals are always weathered, sometimes almost beyond recognition, especially in the older set of dikes.

Hornblende, rather evenly scattered through the sections, is almost as important as plagioclase. It shows its characteristic pleochroism, and in many cases also its typical cleavage angle of about 124°. Sometimes the hornblende is concentrated into small green patches about the size of a pea.

Orthoclase is a minor constituent compared to plagioclase and usually occurs in irregular grains.

Augite is quite abundant in some specimens, while in others it is entirely absent. It usually appears in well-developed crystals showing a brown color, very slight pleochroism, and characteristic cleavage angles of 87°.

Biotite is a minor constituent, but often occurs in the typical brown patches with fine basal cleavage and strong pleochroism.

Iron oxide occurs as occasional opaque irregular grains in all of the sections examined.

A study of the diorites shows a considerable variation of these rocks among themselves. Some contain very little augite and feldspar while they are very rich in hornblende. Such rocks would readily suggest a similarity to the gabbros in basicity. Other diorites contain much less hornblende, but more feldspar and augite, and are the most acid rocks of the series.

Chemical analysis.—The following is a partial analysis of the typical Quarry Hill diorite furnished by the United States Geological Survey to Dr. J. C. Branner:

SiO_2	51.52
Al_2O_3	23.14
Fe_2O_3+FeO	6.17
TiO_2	0.33
CaO	9.58
MgO	1.64
P_2O_5	trace
Total	92.38

THE GABBROS

Occurrence.—Among the igneous rocks of the Oak Hill area the gabbros are smallest in amount. They occur on Quarry Hill and seem to grade over, on the one hand, into the basic pyroxenite-peridotites and, on the other, into hypersthene gabbro or norite. Among themselves the gabbros are very variable in mineral composition. They range from a typical olivine gabbro to a hypersthene gabbro. There is no evidence of intrusion. On the other hand, the field relations together with the microscopic evidence demonstrate a transition into serpentine. A tunnel into the base of Quarry Hill on the north side penetrates the norite for about seventy-five feet. An open cut on top of the hill immediately above this tunnel shows exposures of the same norite. In the field a distinct gneissic structure is noticeable, which in this phase of the rock is scarcely evident in the hand specimen. Outcrops of the other gabbro are irregularly scattered over Quarry Hill, and none are found over the other parts of the area studied.

Petrographic characters.—The gabbro and norite are granitic in texture and of dark-gray color. The typical gabbro is usually medium grained, while the norite is slightly finer-grained. In the hand specimen the plagioclase, olivine and diallage of the gabbro are plainly visible to the naked eye. The plagioclases with their shiny surfaces and the diallage crystals with their greenish shiny faces appear to be unusually fresh. In the norite the plagioclase and the hypersthene are likewise visible to the naked eye. Here the plagioclase appears slightly more weathered than that of the gabbro. The hypersthene occurs in numerous brown crystals evenly scattered throughout the mass.

In marked contrast to the diorites, the minerals in many of these gabbro-norites are clear and fresh. The list of minerals in this series of rocks includes the following: plagioclase, hypersthene, diallage, enstatite, hornblende, olivine, augite, and iron-oxide. Sometimes all of these may be seen in a single section.

Plagioclase, chiefly labradorite, is the most constant of the minerals present. It occurs in clear glassy plates the crystals being usually well-defined. Twinning according to both the albite and carlsbad laws is common. Sometimes pericline twinning was observed. Olivine and hypersthene are occasional inclusions.

Hypersthene is the second most abundant mineral in the typical norite. Very little, or sometimes none, is present in the gabbro. The hypersthene usually appears as allotriomorphic crystals. The pleochroism from reddish-brown to greenish-yellow to green is very distinct. The hypersthene seems generally rather fresh but sometimes it is weathered to a green serpentinous mineral.

Diallage is the next most common mineral in the typical gabbro, but is less abundant in the norite. It appears as large irregular crystals, often blurred by weathering. In ordinary light it varies from nearly colorless to a light green. The fine striations so characteristic of diallage are well developed. The crystals exhibit a metallic sheen and show no pleochroism. In a few instances twinning was noticed. Plagioclase is often included in the diallage, and very often the diallage has grown partially around the plagioclase, thus showing it to be later in formation.

Enstatite is abundant in some of the gabbros. It always occurs without regular crystal boundaries. The highly characteristic columnar structure and the parallel extinction are well shown.

Hornblende is usually absent from the typical gabbro; it is present to only a small extent in the norite; but in sections from a few outcrops it is so predominant that the rocks may readily be called hornblende-gabbro. In the latter rocks much of the hornblende is badly weathered and is altered to cholorite in green patches. The characteristic cleavage lines making angles of about 124° are very distinct in the primary hornblende. It exhibits a pleochroism from a green to a light yellow. Examples of twinning are also quite common.

Common augite occurs in considerable quantity in the norite, but scarcely any is present in the gabbro. The individuals are allotriomorphic and very irregular in shape, but show the usual cleavage angles of 87°. The pleochroism of the augite is from a colorless to a light brown. It may often be seen perfectly twinned. Some inclusions of olivine were noticed.

Olivine is a constant constituent of all the gabbros. In ordinary light it is colorless, while in polarized light it exhibits the characteristic high relief and strong double refraction. The crystals are usually rounded, but are generally much weathered and blurred. It is often serpentinized along irregular cracks that ramify through the crystals.

Magnetite is found in small opaque patches scattered through all the sections of gabbro and of norite.

Relations of the gabbros.—From a study of the field relations and the examination of a number of thin sections it is evident that the different variations of gabbro are merely local. Some of the gabbros have much olivine—olivine gabbro; some have much hornblende—hornblende gabbro; many of the gabbros have abundant hypersthene —hypersthene gabbro or norite; many have a predominance of diallage—normal gabbro.

The typical norite from the cut at the top of Quarry Hill contains much hypersthene, together with some hornblende and augite, while it contains little olivine and diallage. On the other hand, the typical gabbro contains much diallage, but practically no hypersthene, hornblende, nor common augite. Sections have been examined which show almost perfect gradations between these various kinds of gabbro, thus strongly suggesting that they are phases in the differentiation of the same magma.

Those gabbros which are rich in diallage and poor in hypersthene, hornblende, and augite most nearly approach the pyroxenites, next to be described, in constitution. Those which are rich in hypersthene, hornblende, and augite, but poor in diallage, most nearly approach the diorites. Thus the gabbros which undoubtedly represent the most acid end of the interesting basic series of pyroxenites, peridotites, and resulting serpentines may also be a connecting link between these and the more acid diorites. All the above gradations may be observed within a radius of seventy-five yards of Quarry Hill.

Chemical analysis.—Following is a partial analysis of the olivine gabbro furnished to Dr. J. C. Branner by the United States Geological Survey:

SiO_2	48.11
Al_2O_3	14.67
$Fe_2O_3 + FeO$	6.45
TiO_2	0.15
CaO	17.55
MgO	11.19
P_2O_5	none
Total	98.12

THE OLIVINE PYROXENITE

Occurrence.—This rock occurs mainly in and about the quarry, and is made up essentially of olivine and diallage with some magnetite. The percentage of diallage varies from a few scattered crystals, as in the massive varieties of serpentine, to a rock made up almost entirely of diallage. The olivine is never wholly free from the process of serpentinization, except in the gabbro phase of the rock, and usually no feldspar is present. It is evidently a phase of the serpentine, the difference being chiefly in the relative proportion of the olivine and diallage.

Petrographic characters.—A gneissic structure common to the gabbros is also, in this rock, very perfectly developed, and is accentuated at the surface by weathering. The diallage crystals are generally nearly a centimeter in length and quite uniform in size. Their cleavage surfaces are brassy in appearance, in some cases quite dark. When near the serpentine phase the whole rock becomes dark, resembling the massive serpentine. On the southeast side of the quarry entrance the rock is practically a diallagite, of a greenish-yellow color. On the south face of the quarry this rock contains feldspar and fresh olivine, thus passing into the gabbro phase. The optical properties of the diallage and olivine are the same as in the gabbro.

THE PERIDOTITE-SERPENTINE

Occurrence and associations.—Serpentine forms the greater part of the Oak Hill area and can be traced almost continuously severa

miles along the Los Lagrimas Hills southeast to the Mount Hamilton Range. It is about eleven miles from the serpentine of the New Almaden region described by Becker.[1]

In most respects it is similar to the serpentine of the San Francisco Peninsula, Angel Island, Crystal Springs Lake, and numerous other occurrences in the Coast Ranges; and it is probably identical in age with them. It is associated with radiolarian cherts and sandstones which belong to the formation described by Professor Lawson[2] as San Franciscan, and by Dr. H. W. Fairbanks[3] as Golden Gate.

The serpentine mass here represents an intrusion in the nature of a boss or very large dike. The outcrop reaches a width of one and a half miles. The extent below the surface cannot be determined because in most places it is buried beneath the alluvium which covers the valley floor.

The prevalence of schist about the periphery of the serpentine, together with the fact that the jaspers, where they occur, are frequently contorted and otherwise altered, would suggest that serpentine was capable of affecting to a considerable degree the rocks into which it was intruded; yet this evidence is not conclusive.

Petrographic characters.—The serpentine varies greatly in character. It typically consists of crystals of diallage imbedded in a groundmass varying in color from a light to a dark green, consisting chiefly of the mineral serpentine, in which are numerous grains of magnetite. Enstatite and iron-pyrites are found very sparingly, while a large portion of the slides show residual grains of olivine. The process of serpentinization is also observed in some of the imbedded diallage crystals working in along the cleavage planes from the outside to the center, although this mineral is usually fresh.

This massive phase of the peridotite-serpentine varies in composition from a rock, in which the glistening face of a diallage crystal may be seen here and there imbedded in serpentine, to one made up essen-

[1] *Geology of the Quicksilver Deposits of the Pacific Slope*, Monograph XIII, U. S. Geological Survey.

[2] *Geology of the San Francisco Peninsula*, Fifteenth Annual Report, U. S. Geological Survey.

[3] "The Stratigraphy of the California Coast Ranges," *Journal of Geology*, Vol. III (1895), pp. 415-33.

tially of diallage, the latter presenting an uneven fracture, while the former is a compact rock with a conchoidal fracture.

The mesh structure is common, especially in the compact conchoidal variety, while grains of olivine and minute crystals of magnetite are disseminated throughout the whole mass. The minute crystals of magnetite may be detected in the groundmass by the aid of a pocket lens, and are so numerous that the fine powder of the crushed serpentine will immediately jump to a magnet. These magnetite crystals are chiefly concentrated along the lines common to contiguous meshes, but are at times also found along with serpentine, making up dark anastomosing veins, attaining in some instances half an inch or more in width.

Genesis of serpentine from peridotite.—The structure and mineralogical composition of this serpentine then clearly indicate that it was derived from a basic rock in which olivine was the predominating mineral together with diallage and magnetite. The peridotite from which the serpentine was derived is not found in a fresh condition. It is interesting, however, to note that in the phases of the rock in which diallage predominates we do have a comparatively fresh rock, which fact confirms the igneous origin of the serpentine.

Chromite.—Several somewhat irregular pockets of chromite in peridotite-serpentine occur in the Los Lagrimas Hills, never exceeding a few feet in extent. The relative hardness of the ore in some cases caused it to stand up above the surrounding surface. On this account it attracted attention, and formerly on the Swickard ranch near the Coyote Creek, these occurrences were mined, and the product shipped east. So intimately associated is the serpentine with the chromite that it is difficult to secure from these prospect holes a hand specimen of the ore that does not contain serpentine. It would seem as if the chromite is a product of differentiation from the serpentine.

Cinnabar.—The San Juan cinnabar mine occurs on the Oak Hill area. Here the ore occurs along joint planes and zones of faulting, the impregnations extending some distance from the walls into the serpentine and its alteration products. Extensive mining is not now carried on in this region, though operations are now being conducted in a small way.

At the Silver Creek mine, four miles south of Evergreen, in appar-

ently this same range of serpentine, the conditions are very similar. It would appear that formerly comparatively extensive mining operations were carried on at both these places.

Analysis of serpentine.—The analysis of this serpentine was furnished by the United States Geological Survey at the request of Dr. Branner. The other analyses of Coast Range serpentines are given for comparison.

	I	II	III
SiO_2	37.71	39.60	42.06
Cr_2O_3	.....	0.20	.....
Al_2O_3	1.81	1.94	2.72
Fe_2O_3	10.47	.....	.....
FeO	.....	8.45	2.88
MnO	.....	.....	.....
MgO	35.60	36.90	39.53
Na_2O	(not	determined)	
TiO_2	0.09	.....	.....
H_2O	(not det.)	12.91	12.04
Total	85.95	100.00	99.23

I. Massive conchoidal serpentine of the Oak Hill area, by United States Geological Survey for Dr. Branner.

II. Serpentine from Presidio, San Francisco; analyst, Dr. Easter. *Pacific Railroad Reports*, Vol. VI [1855]. (Pt. 2, p. 11.)

III. Serpentine hard sound nodule in crushed matrix; analyst, Dr. F. L. Ransome. ("The Geology of Angel Island," *Bulletin of the Department of Geology of the University of California*, p. 231.)

Analysis No. 1 (United States Geological Survey) confirms the conclusions reached above. The original rock was evidently ultrabasic. The large percentage of iron is doubtless accounted for by the presence of the mineral magnetite, while the mineral serpentine makes up a large part of the remainder of the rock. The proportion of silica to magnesium also approaches that ratio in the pure mineral serpentine, in which 40.42 per cent. of magnesium corresponds to 41.52 per cent. of silica. The evidence is clear that the serpentine is an altered igneous rock. On some of the slopes of the Oak Hill area, where both sandstone and serpentine are exposed, a mechanical mixture of serpentine and sand has been formed.

SLICKENSIDED SERPENTINE

This aspect of the serpentine in most respects closely corresponds to that described by Dr. Palache.[1] The rock is varied in character, being found from a gray to a light green shade, and is quite soft. The plane slickensided faces, often greasy and striated, predominate over curved faces, so that in many places it has a foliated or schistose structure. This phase occurs in rather extensive zones which appear to be fault zones, and also along joint planes in the peridotite-serpentine, which are frequently planes of movement. In some cases the slickensiding has extended out from the joint planes, involving the peridotite-serpentine until it remains as a core in the center of the slickensided variety.

While at the Potrero the massive facies is very subordinate in amount, in the Los Lagrimas Hills and the Oak Hill area the reverse is the case, and the bowlders are represented in a few places in the beginning stages of formation.

MOTTLED SERPENTINE

Associated with the massive green serpentine in and about the quarry occurs a light green facies in which roundish light colored areas are found in the green or grayish-green variety making up about half the rock, and giving to it a very striking and mottled appearance. The light spots vary in size from points barely visible to the size of a hen's egg or even larger. The microscope shows that the mesh structure is present in the least decomposed parts of the white areas and is continuous from the contiguous green part, in some cases gradually disappearing as the center of the white area is approached. Small magnetite crystals are also present, though not so numerous, and have a similar distribution. Often small cores of the greenish serpentine occur within the white areas, frequently near the center.

Qualitative analysis demonstrated abundant silica and magnesium, indicating that it is essentially magnesium silicate, and that it is derived from the mineral serpentine by secondary changes, possibly accompanied by the leaching out of iron. The frequent occurrence of this white material in veins, and the fact that the surface of the

[1] "The Lherzolite Serpentine and Associated Rocks of the Potrero," *S. F. Bulletin of the Department of Geology of the University of California.*

greenish variety weathers to this same product, would tend to confirm this view.

These patches disintegrate on exposure more readily than the massive green variety, and in some instances accentuate the very irregular and fantastic forms that result from surface weathering.

This change of the mineral serpentine to magnesium silicate, which is common in serpentine areas, seems to be an intermediate one, and frequently precedes the release and subsequent deposition of silica and the taking-up of carbon dioxide, thus forming a rock made up of carbonates and various forms of silica, together with compounds of iron, etc. Such a rock occurs quite abundantly in the vicinity of the Oak Hill area, and will now be described.

"SILICA CARBONATE SINTER"

Its occurrence in the serpentine appears to be somewhat sporadic, and there is no fixed evidence to indicate that it is either an inclusion, a dike or a vein. On the other hand, it seems to bear relationships with the serpentine with which it is found and into which it grades. At times it occurs in the form of a dike or vein, but may be irregular in outline. The alteration in some cases is so complete that the rock has many characteristics of a vein.

Petrographic characters.—Professor Lawson described what is evidently this same rock under the tentative name "Silica-Carbonate Sinter,"[1] and his description applies so well that I quote it here:

> Petrographically the rock is an exceedingly irregular and intricate mixture of silica in the form of opal and chalcedony and carbonates of lime, magnesia, and iron. The silica is present usually in the form of a mesh-work of veinules, which, however, do not seem to fill fissures in the carbonate, but to be of contemporaneous formation with it. These veinules anastomose, but do not commonly intersect, and they vary greatly in their thickness. In weathering, the carbonate of iron yields an abundant ochre, the other carbonates are leached out, and the silica remains as a honeycombed mass, giving rise to exceedingly irregular and fantastic, pitted and cavernous forms, which project ruggedly above the general surface. It is difficult to get a fresh mass of the rock quite free from the yellow ochre. In the least decomposed specimens the carbonates are seen to have the crystalline texture of marble with a yellowish color. Occasionly there is a bright green strain apparent in the rock which may be a silicate of iron.

[1] "Geology of the San Francisco Peninsula," *Fifteenth Annual Report of the U. S. Geological Survey*, p. 435.

In a recent letter to Mr. Carey referring to the genesis of his rock, Professor Lawson says:

> I have seen a good deal of that so-called "Silica-Carbonate Sinter," since I wrote my paper on the geology of the San Francisco Peninsula, and have established to my own satisfaction that the rock in question is an alteration product of serpentine, and that the cases where it appeared to be interbedded must be cases of intrusive sills. It is thus a chemical rock, but due to alteration, and I think the term "Sinter" therefore a misnomer and will not myself use it.

This rock, then, is the final or end product of an interesting chemical transformation in connection with serpentine. It possesses the composition and properties that would be predicted for it apart from any evidence. Remnants of serpentine have been found in this rock, and all stages in the transformation observed.

THE GLAUCOPHANE SCHISTS

The glaucophane schists of the Oak Hill area and vicinity occur as distinct outcrops on the southern and eastern portion of the hills, in general near the periphery of the serpentine. They present nearly as many facies as there are occurrences. It is difficult to observe contact phenomena, but in one instance at least it appears that the glaucophane schist is completely surrounded by serpentine; two other outcrops are closely associated with, if not actually in contact with, jasper; while still in another, glaucophane schist is in the immediate vicinity of sandstone and appears to grade into it.

The glaucophane schists of the Oak Hill area may be described under three heads.

1. *The ordinary typical glaucophane schist.*—In this facies the schistosity is eminently developed, and the schist can be readily split into large thin pieces. It is uniformly bluish in color, and contains flakes of mica which are plainly visible to the naked eye.

The microscope shows this rock to be made up essentially of glaucophane, with some mica, lawsonite, and titanite. The glaucophane prisms show the well-established glaucophane orientation. In the glaucophane the $\mathfrak{a}$ ray is pale greenish-yellow; the $\mathfrak{b}$ ray is purplish-violet parallel to the long diagonal of the basal sections; the ray is sky-blue, and the inclination of $\mathfrak{c}$ to C' is about 8°. The absorption is $\mathfrak{b} < \mathfrak{c} > \mathfrak{a}$. In addition to the prism, clinopinacoidal

faces were observed on many crystals. The cleavage parallel to the prism is perfect with angles of about 124.°

The lawsonite crystals are comparatively fresh and occur in considerable quantity. A good outcrop of this rock is found near the present workings of the San Juan mine.

2. *The garnetiferous schist.*—The chief difference between this and the typical schist is the relatively smaller amount of glaucophane, the development of numerous garnets, and a somewhat less marked schistosity, the rock being more massive. The garnets, which are irregularly distributed throughout the rock, average about one millimeter in diameter, and can often be detected with the unaided eye. The mica flakes, which are also unevenly distributed, are small, but very numerous. It has been mentioned as eclogite by Mr. R. S. Holway.[1]

The microscope reveals the presence of much garnet and chlorite, some lawsonite, actinolite, glaucophane, and usually also white mica. The garnets usually appear in well-defined crystals, showing high index and high relief. The individuals are nearly always strongly fractured and the cracks filled with green chlorite. In ordinary light the garnets are light reddish-brown in color. The lawsonite is scarce in this rock, appearing as small weathered patches. The green chlorite occurs in abundance in rough, irregularly shaped patches. The glaucophane is not abundant; it occurs as small blue prismatic crystals with properties as described in the typical schist. The mica, like a garnet, is unevenly distributed through the rock. It is of a slightly brownish tint and is probably paragonite.

3. *The acid or quartz-bearing schist.*—The most highly acid exposure of this type of schist was found in close proximity to highly altered banded jaspers in which the typical features, including the banded structure, had disappeared, and the rock was identified only by the presence of radiolaria as shown by the microscope.

The schist is massive and made up almost entirely of silica in indistinct bands of variable thickness, with a little mica on the surfaces. The microscope, however, shows in the slide here and there a deep blue prism of glaucophane imbedded in the silica, and innumerable minute pink dodecahedral garnets.

[1] "Eclogites in California," *Journal of Geology*, Vol. XII, No. 4. (1904), p. 354.

In other instances the rock appears to be a mica schist, with free quartz intercolated irregularly between the planes of schistosity. The bands are crumpled, and the crystals of glaucophane are broken, distorted, and frequently healed with quartz.

Suggestions as to origin.—The close association of the glaucophanes with the jaspers and sandstones would suggest a genetic relationship. According to F. L. Ransome,[1] the glaucophane schists of Angel Island, San Francisco Bay, are the result of the metamorphism of the radiolarian cherts as well as the feldspathic sandstones. The schist there consists of quartz, albite, glaucophane, biotite, etc. Some of the Oak Hill rocks are very similar to those in composition. This close association of the glaucophane schists and jaspers has been commonly observed in the Coast Ranges of California.

Some of the Oak Hill glaucophane schist is rich in argillaceous matter. Near the border of this schist fairly large flakes of a light brown mica have been developed, while nearer the center of the mass little or no mica appears.

Although no positive general statement can be made with reference to the origin of the glaucophane schist, nevertheless it is certain that at least in some cases they are the products of the metamorphism of sediments. This is undoubtedly true of the more siliceous facies, while the more basic facies may have resulted from the alteration of tuffs of ingneous rocks. Ransome ascribed their origin to contact metamorphism, while Nutter and Barber[2] thought that dynamic metamorphism alone could account for the origin of the greater schist masses of the Coast Ranges. It would appear that further investigation along the line of mineralizing effects of solutions in metamorphic zones is necessary to explain the genesis of glaucophane and associated minerals.

MAGMATIC DIFFERENTIATION

In the foregoing description of the gabbros, pyroxenites, and serpentines with their products, it has been pointed out that, while all the rock types are very distinctly shown, nevertheless the transitions are

[1] *Bulletin of the Department of Geology of the University of California*, 1894, pp. 193–240.

[2] *Journal of Geology*, Vol. X, No. 7 (1902), p. 742.

so evident that it has been found artificial to make separate classes. The field indications show conclusively that the pyroxenite grades into the typical gabbro on the one hand, and into the olivine-pyroxenite on the other. Further, this olivine-pyroxenite, which in one phase is practically a diallagite, in other phases goes by insensible gradations into peridotite-serpentine; that is, the phase of the pyroxenite, richest in olivine (peridotite) has become serpentinized and gives us peridotite-serpentine and serpentine.

This serpentine, it has been suggested, gives up its iron, yielding veins of magnesium-silicate, which in turn liberates silica, takes up carbon-dioxide, forming magnesium-carbonate. Thus we find over the area the free oxides of iron veins and patches of magnesium-silicate, and, where conditions favor the taking-up of carbon-dioxide, magnesium-carbonate. When the carbonates, silicates, free silica, and iron-oxides are all mixed in one complex rock, we get a product that has been described under the name "silica carbonate sinter."

The hypersthene gabbro in the field has not been observed in direct connection with the other rocks of the gabbro-pyroxenite-serpentine series; it, however, shows no evidence of intrusion. It is in very close proximity to the typical gabbro, and is found nowhere else over the area. Its mineralogical variation, moreover, would lead to the conclusion that it is but a phase of the ordinary typical gabbro.

Olivine, it has been noted, is common to all this rock series, increasing in freshness from the serpentine to the hypersthene-gabbro. These rocks also have a banded structure in common. The mineral diallage is also common to all the rocks of the series. Its ratio to olivine accounts for the variations from diallagite, olivine-pyroxenite, peridotite-serpentine to serpentine. In acidity we have an increase from 37.71 per cent. of silica in the serpentine to 48.11 per cent. in the gabbro.

The authors, in conclusion, wish to express their thanks to Dr. J. P. Smith, for his constant aid and advice; to Dr. J. C. Branner, for the chemical analyses secured from the United States Geological Survey. Mr. F. H. Tibbetts, a former student of Mr. Carey's, aided materially in the construction of the topographic map.

SOME OBSERVATIONS ON THE MOVEMENTS OF UNDERGROUND WATER IN CONFINED BASINS

A. R. SCHULTZ
U. S. Geological Survey, Washington, D. C

In 1905, while pursuing my geologic studies at the University of Chicago, I had an opportunity of doing some experimental work on the motion of underground waters in confined basins. Although the time and equipment for experimentation were limited, an attempt was made to ascertain as nearly as possible from a given set of conditions what effect distance from the outcrop area has upon the flow or yield of a well; how an increase in head modifies the flow or yield of a well; with what regularity friction increases as the distance from the outcrop area is increased; and what effect confined air between the water table and a surface layer of water has upon the water level in a well. It is not supposed that any rigid deductions can be made from a set of single experiments. It is necessary, before making such deductions, that several kinds of material be tested under somewhat different conditions to see whether or not they agree in the essential points. For this reason no deductions will be made, but the facts observed in the experiment are recorded and may be compared with known conditions in other artesian basins.

To determine the above factors a miniature artesian basin was arranged in the basement of Walker Museum and the experiment begun. The basin consisted of an eight-inch steam pipe 40 feet long, and closed at one end. The pipe was placed in position as shown in Fig. 1, and then filled with clean, dry sand, packed as firmly as possible by tamping the sand with a rod as the pipe was being filled. Five ⅜-inch wells were drilled at points *A*, *B*, *C*, *D*, and *E*. In each of these wells was inserted a casing ¼-inch in diameter and 9 inches long. The lower 8 inches, which extended down into the sand consisted of a cylindrical wire screen, surrounded on the outside by one thickness of cheese-cloth to prevent the finer sand grains from being washed into the well and filling it. The upper portion of the casing, which projected through the steam pipe and furnished the ground connection of the well, was a cylindrical brass tube ¼-inch in diam-

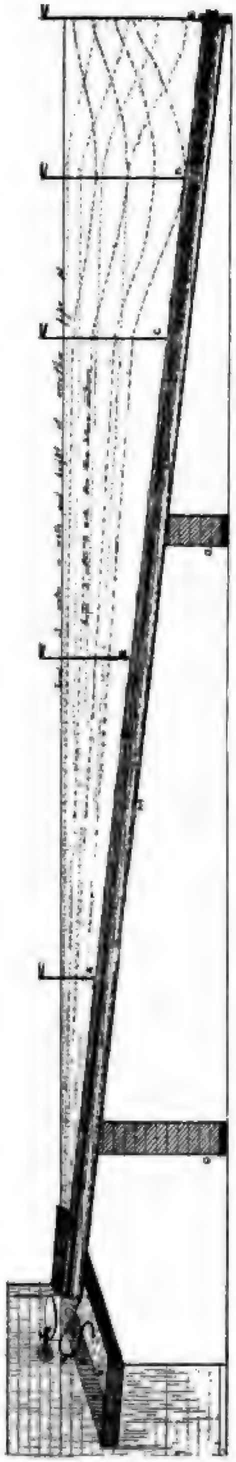


FIG. 1.—Diagram showing the arrangement of a miniature artesian basin.

eter and one inch in length, to which the lower 8 inches were soldered. When the casing was in place the remaining space in the well outside the casing was filled with sand and the space between the brass well casing and the iron pipe sealed, making a water-tight contact and leaving no passage for the water within the iron pipe except through one of the five wells. Above ground or outside the iron pipe each well casing was connected with ¼-inch rubber tubing, long enough to extend higher than the intake of the iron pipe. To facilitate reading the height to which the water in the well rose and to make it easier to collect the water flowing from the wells, the end of each tubing was provided with a foot of ¼-inch glass tubing bent at right angles as shown in diagram.

With the apparatus in position as above shown, the water was turned on and the sand within the pipe allowed to absorb as much water as possible—the surplus escaping through the overflow pipe *N*. In order to ascertain with what velocity the water flowed through the pipe the tubing at well *E* was disconnected at the brass casing and an indicator to report the final arrival of water inserted into well *E*. The time from the turning on of the water until it arrived at *E* was found to be 25 hours and 40 minutes. The velocity was therefore 1.56 feet per hour or .31 inches per minute. The average diameter of the sand grains as determined by measurement of 1,000 grains was .43 ^{mm} and the porosity of the sand 39.2 per cent.

The tubing at well *E* was replaced and in a short time the water in each well stood

at the same level as the overflow pipe. The basin was saturated, the water ponded, and no more water entered the sand, but all escaped through the overflow pipe.

It was believed that the water flowing through the pipe would readjust the sand particles and succeed in packing them into smaller space than was done on filling the pipe with sand. To accomplish this the well tubing at each well was placed in a receptacle on the floor of the basement, and the water allowed to flow freely from the wells. At short intervals the pipe was revolved in order to assist in packing the sand. This process was continued for two days, and as the sand settled in the pipe a new supply was added at the intake. When the pipe was entirely filled and no further settling took place the wells were put back in position shown in Fig. 1, and the water in the wells soon stood at the level of the overflow pipe. A constant head was maintained at the intake by allowing enough water to flow so that a small stream or the surplus water escaped through the overflow pipe.

Tests were now made to ascertain the yield per well at different heads. The water at one of the wells was allowed to flow at a given head until the flow became constant. The head was then increased and maintained until the flow again became constant, and so on until each well in turn was tested.

The test at each well was begun only after the water in all the wells stood on a level with the overflow pipe and they were, therefore, independent of each other. The flow or yield per well at a given head was determined by collecting the discharge per minute, as timed by a stop watch, and weighing the water thus collected. The results obtained in this test are set forth in the tables appearing on the following pages.

Another series of tests were made similar to those in Table I. This time, however, the flows at the various wells were not given time to become constant. Each measurement at the five wells was taken only after the water in all the wells stood on a level with the overflow pipe. After each measurement time was allowed for the water to regain its normal condition. The figures therefore in this table indicate the flow during the first minute after the well is allowed to flow at a certain head.

TABLE I

SHOWING DECREASE IN FLOW DURING THE FIRST STAGES OF PRODUCTIVE WELL AND THE INCREASED YIELD DUE TO INCREASED PRESSURE

Well	Time Interval at Which Flow Was Tested	Flow in Grams per Minute			
		1 Ft. Head	2 Ft. Head	3 Ft. Head	4 Ft. Head
	Minutes				
A	0	245			
	10	220			
	20	195			
	30	165			
	40	142			
	50	120			
	60	110			
	70	100			
	80	91			
	90	82			
	100	84			
	110	82			
	120	82			
B	0	216	365		
	10		330		
	20	198	305		
	30	180	285		
	40	166	256		
	50	150	225		
	60	135	205		
	70	115	182		
	80	99	166		
	90	89	161		
	100	88	159		
	110	89	159		
	120	89	159		
	130	89	159		
	Increase in flow		70 g or 79%		
C	0	215	325	370	
	10	199	308	346	
	20	190	291	324	
	30	172	271	310	
	40	160	252	289	
	50	151	230	278	
	60	145	215	265	
	70	136	198	252	
	80	116	184	245	
	90	106	170	237	
	100	99	164	236	
	110	91	162	237	
	120	91	162	235	
	130	91	165	236	
	Increase in flow		74 g or 81%	71 g or 78%	

TABLE I—*Continued*

Wells	Time Interval at Which Flow Was Tested	Flow in Grams per Minute			
		1 Ft. Head	2 Ft. Head	3 Ft. Head	4 Ft. Head
D	0	225	351	390	420
	10	195	332		
	20	180	310	345	
	30	160	290	330	370
	40	150	270	315	356
	50	138	240	289	340
	60	123	220	268	328
	70	110	205	252	310
	80	100	190	228	208
	90	92	172	222	290
	100	91	129	219	286
	110	90	154	220	284
	120	89	154	220	284
	130	90	154	220	284
	Increase in flow		64 g or 71%	66 g or 73%	64 g or 71%
E	0	166	179	198	215
	10	140	155	172	203
	20		122	160	192
	30		105	151	180
	40	64	96	140	171
	50	56	95	128	160
	60	50	83	120	156
	70	48	83	115	152
	80	48.2	83	115	150
	90	48.3	83		150.2
	100	48.2		115	150.4
	110	48.2			
	120		83	115	150
	130	48	83	115	150
	Increase in flow		35 g or 73%	32 g or 67%	35 g or 73%

On examining the above two tables it is evident that the flow at each of the wells for a given head is about the same. Well *D* at a given head furnished as much water as well *A*, *B*, or *C*, although its distance from the outcrop is much greater. Well *E* is the only exception. The decrease in yield here is due, no doubt, to the nearness of the well to the end of the pipe which greatly reduces the area supplying the well.

The flow or yield per well does not increase at the same rate as the pressure but lags somewhat behind. As determined from the various measurements recorded in Tables I and II, the flow or yield per well approximates 73 per cent. of the increase in pressure or head. In other words, doubling the head increases the flow by about 73 per cent. In a test made by Professor Turneaure for the Madison waterworks

TABLE II

SHOWING THE INCREASE IN FLOW DUE TO INCREASE IN HEAD

WELLS	FLOW IN GRAMS PER MINUTE			
	1 Ft. Head	2 Ft. Head	3 Ft. Head	4 Ft. Head
A.....	245 Increase in flow			
B.....	216 Increase in flow	388 172 or 71 %		
C.....	215 Increase in flow	383 168 or 78%	540 157 or 73%	
D.....	225 Increase in flow	390 165 or 73%	555 165 or 73%	710 155 or 72%
E.....	166 Increase in flow	279 113 or 68%	397 118 or 71%	516 119 or 71%

Commissioners in 1903 the capacity of the Main Street well (No. 10) at Madison, Wis. (see Fig. 2), was found to be 599,000 gallons per day when the water stood 18 feet below the surface. On lowering the water to a depth of 72 feet below the surface the yield was increased to 1,500,000 gallons per day, the increase in flow being only 63 per cent. of the increase in head.

Table I shows that the flow at any well was at a maximum when the well was first tapped or allowed to flow. The flow then gradually decreased and finally became constant. During this decrease in flow the water in the remaining wells gradually lowered and readjusted itself. The final position of the water in the wells after the flow became uniform in wells *D* and *E* is shown by the dotted lines in Fig. 1. The greater flow during the first stages is probably due to the fact that the water immediately adjacent to the well finds ready entrance into the well with comparatively little friction. As the water farther from the well is drawn upon, the friction becomes greater and greater as the distance the water moves through the sand particles increases, and the yield consequently less and less. Finally the well adjusts itself to its new conditions of head and friction, and the yield becomes fairly uniform.

The point of interest here is that the wells farthest from the intake yield as strong a flow as those one-third or one-fourth the distance

from the intake. This suggests that the friction which is the cause of cutting down the flow is restricted largely to the vicinity of the well where the water is moving with the greatest velocity. Much the same conditions probably exist in the Wisconsin artesian basin, where in the vicinity of Green Bay, Milwaukee, Wis., and Chicago, Ill., the head has been reduced approximately 100 feet since the first flowing wells were put down, while many of the wells between these locations and the intake area have practically the same head as when first drilled. Recent wells drilled between the above-named localities and the outcrop region show that there is no corresponding decrease in head to that noted in the vicinity of Green Bay, Milwaukee, and Chicago. It follows, therefore, that through the major distance of the sandstone the friction of the water is almost zero, or the pressure at the wells would not so nearly equal the pressure due to head.

When wells are allowed to flow or are heavily pumped, the pressure in the vicinity of the well rapidly drops, while at a distance of several thousand feet the pressure is often as great while the well is flowing or heavily pumped as it was before the flow or pumping began.

That the influence of a well extends to a very considerable distance is shown in a general way by the following tests made in Madison, Wis., by the Waterworks Department in 1903 (for location of wells see Fig. 2):

	No. Gallons per Day
1. One well at the pumping station yields	500,000
2. Four wells at the pumping station yield	1,000,000
3. Four wells at the pumping station, and four wells scattered along a line 3,000 feet long yield	1,750,000
4. Four wells at pumping station and one remote well yield	1,300,000
5. Main Street pump (Well No. 10), not running the Blount Street well (No. 8), yields	984,000
While the remainder of the wells yield	2,240,000
6. Main Street and Blount Street pumps both running, the two wells yield	1,944,000
(or nearly twice the yield of the Blount Street well in Par. 5) while the remainder of the wells yield	1,300,000

When the Madison wells were first drilled the water overflowed 4.5 feet above Lake Mendota, or 854.5 feet above tide. At present propeller pumps are installed at the Main Street well (No. 10) and

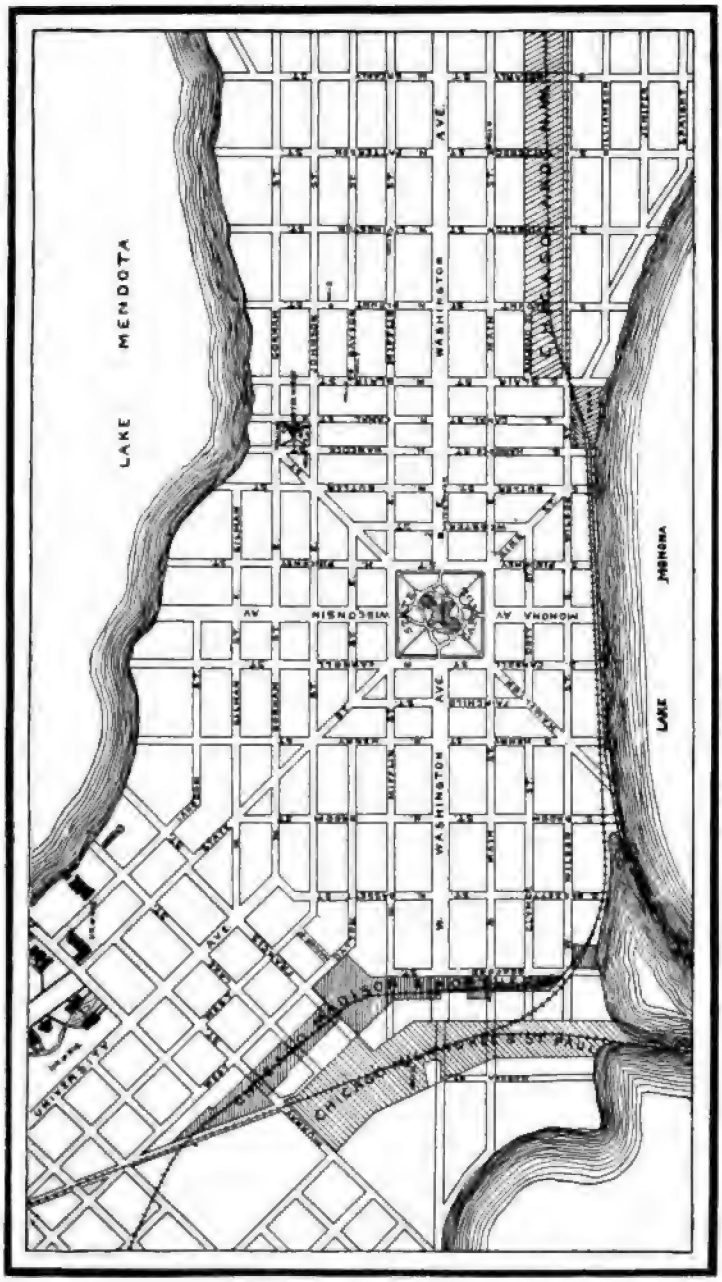


Fig. 2.—Map showing the location of artesian wells in Madison, Wis.

DESCRIPTION OF FIG. 2

		Diameter	Depth	Owner
Well	1	8 inches	751 feet	City of Madison (Waterworks)
"	2	8 "	226 "	
"	3	6 "	751 "	
"	4	6 "	751 "	
"	5	8 "	751 "	
"	6	8 "	751 "	
"	7	8 "	226 "	
"	8	8 "	751 "	
"	9	10 "	821 "	
"	10	10 "	736 "	
"	11		1015 "	State of Wisconsin
"	12		795 "	Chicago, Milwaukee & St. Paul Ry. Co.

Blount Street well (No. 8). All other wells (see Fig. 2) are connected with the suction of the pumps at the pumping station. The Main Street well is scarcely affected, while the pumps at the pumping station, with a vacuum of about 18 inches, are drawing water. The nearest well of the group, the Livingston Street well or No. 9, is only 1,000 feet from the Main Street well No. 10. When the Blount Street propeller pump is working and the water in the well lowered 72 feet, the water in the Main Street well, 2,000 feet from the Blount Street well, recedes about 14 feet, and then remains stationary. Tests of well No. 12 at the C. M. & St. Paul roundhouse, a mile distant, fail to show any effect of the pumping at the city well, even while the water in the wells No. 10 and No. 8 was 72 jeet below the surface and the total capacity of all the wells was 3,200,000 gallons per day.

As clearly indicated by the experiment and by the above tests the drop in the water level in the vicinity of a well is not due so much to the friction through the major course of the water where the movement is slow, but is chiefly due to the friction in the vicinity of the well, where the water is moving on its way to the well and on through the casing itself until it reaches the surface. Back a short distance from the well the water oozes slowly from the small openings and maintains the same head as before the well was pumped or allowed to flow.

Several tests were made to see what effect confined air between the water table and the gathering ground would have upon the water level in the wells. During this experiment well *A* was sealed so that no air could escape through it. The water in the pipe stood 1 foot 2 inches below the escape pipe, when water was turned on and the

sand at the outcrop allowed to absorb as much of the water as possible. Ten minutes after the water was turned on the water in the wells stood 1 foot below the escape pipe, indicating a rise of the water in the wells of two inches. Occasionally air bubbles would escape at the intake, causing a slight fluctuation of the water in the wells. On opening well *A* and allowing the air to escape, the pressure of which was strong enough to force paper away from the mouth of the well, the water in the wells *B*, *C*, *D*, and *E* dropped back to its original level, 1 foot 2 inches below the escape pipe, thereby showing that none of the water recently added to confine the air had reached the water table.

The water in the pipe was now lowered to 2 feet 11 inches below the overflow pipe, the other conditions being the same as in the first test. Ten minutes after water was turned on, the head at wells *B*, *C*, *D*, and *E* was 2 feet 9 inches below the overflow pipe. The pressure on the confined air increases as the sand absorbs more water, and when the pressure becomes great enough some of the air rises through the sand and water and escapes at the outcrop. The instant a large bubble of air escapes there is a very slight drop in the water level in the wells.

Thirty minutes after the water was turned on the water in the wells *B*, *C*, *D*, and *E*, stood 2 feet 8.5 inches below the escape pipe, indicating a rise of 2.5 inches. On opening well *A* and allowing the confined air to escape the water in wells *B*, *C*, *D*, and *E* dropped back to 2 feet 11 inches, thereby indicating that none of the recently added water had been added to the water table. The rise of the water in the wells in both of these cases was therefore due to the confined air between the water table and the newly added water layer near the intake; a condition which to a greater or less degree prevails during every rain storm, when the water absorbed by the surface shuts in more or less air between the surface layer of water and the water table. The effect of this additional pressure upon the yield at springs or wells is evident.

In a region of flowing wells like that of southern Wisconsin and northern Illinois where the porous beds are saturated with water and the water more or less ponded, the yield at any given well depends largely upon the conditions of the beds in the immediate vicinity of

the well, and not so much upon the transmitting power of the porous beds between the well and the outcrop area. As indicated by the tests in this experiment, as well as in the Madison test above cited, the disturbance caused by the water, escaping at a well, soon dies out as the distance from the well becomes greater and greater. Seldom in the Wisconsin district does the disturbance extend more than a mile back from the well.

The movement of the water in these ponded basins is very slow. In the Wisconsin area where the annual precipitation approximates 30 inches, probably not more than one fifth or 20 per cent. of this amount is added to the ponded sea. On the other hand it may be considerably less than 20 per cent., for no accurate determinations are at hand which give the exact amount of run-off in the Wisconsin region. To the amount of immediate run-off must also be added the amount that returns to the surface by evaporation, by vegetation, springs, and shallow wells.

Assuming, however, that 20 per cent. is a fair estimate of the amount of precipitation that is added to the ponded sea and that $16\frac{2}{3}$[1] is the average pore space of the Potsdam sandstone, we can compute the rate of flow.

In order that 20 per cent. of the precipitation may be added to the ponded sea without raising the water level, the increment of the previous year must have moved vertically downward 3.6 feet.

The dip of the Potsdam sandstone as indicated by wells between Madison, Wis., and Chicago, Ill., is about 12 feet per mile. It follows, therefore, that the lateral movement of the water amounts to 1760 feet per year or one-third of a mile. As much of the Potsdam sandstone gathering ground lies 200 miles northwest of Chicago, it is evident that the water collected by the catchment area will require in the neighborhood of 600 years before it reaches Chicago. If the average pore space of the sandstone is larger than $16\frac{2}{3}$, the downward movement of the water as above computed would be less, and if the pore space was smaller, the downward movement would have to be greater, in order to hold the 20 per cent. of the precipitation. It also follows

[1] C. R. Van Hise, "A Treatise on Metamorphism." Monograph 47. *U. S. Geological Survey*, pp. 585–89.

that the coarser the sandstone and the more porous, the greater will be the amount of water available at any given well.

That the pore space in many cases is larger is evident. For example in the Prairie du Chien well, drilled in 1903, for the Sanitarium, a coarse bed of sandstone was entered at 720 feet below the surface and continued down to 805 feet, passing through 85 feet of coarse porous sandstone. The pore space of this sand as determined by the writer from several samples taken from the well was found to be 30. The size of the sand grains were very large, making this 85 feet horizon by far the strongest flow of water struck in the well. The average size of grain as determined by measuring 1,000 representative grains was $.92^{mm}$.

The maximum and minimum dimensions of eleven of the larger grains are tabulated below and give a fair idea of the coarseness of the sand grains.

TABLE III

DIMENSIONS OF SAND GRAINS IN POTSDAM SANDSTONE, PRAIRIE DU CHIEN, WISCONSIN

	Minimum Dimension	Maximum Dimension	Average
1......	2.43^{mm}	5.35^{mm}	3.98^{mm}
2......	3.32	3.47	2.39
3......	2.30	3.26	2.78
4......	2.00	3.30	2.60
5......	1.29	3.38	2.34
6......	1.80	2.93	2.36
7......	1.70	3.08	2.39
8......	1.51	3.22	2.37
9......	1.50	2.84	2.17
10......	1.55	2.70	2.12
11......	1.60	2.56	2.08
			2.50

EDITORIAL

The spirit of seismological research has more than once been awakened by a great disaster. The Mino-Owari earthquake in Japan, which occurred in October 1891, and was the most disastrous in more than thirty-five years within that seismically classic province, gave birth to the famous Earthquake Investigation Committee, known as the E. I. C. Its objects were announced to be: (1) "*to investigate whether there are any means of predicting earthquakes;*" and (2) to see "*what can be done to reduce the disastrous effects of earthquakes to a minimum.*" After more than fifteen years of research, to which the ablest minds of Japan have contributed, it is necessary to admit that it is only the last-mentioned endeavor which has been crowned with success.

In 1896 the Committee on Seismological Investigations of the British Association for the Advancement of Science, whose founder and energetic secretary is Professor John Milne, made its first report replacing an earlier standing committee which reported upon the volcanic and earthquake phenomena of Japan. In the following year the well-known *Erdbebenkommission* of the Vienna Academy of Sciences was founded. The value to the world of science of the three committees above mentioned it would be difficult to estimate.

The disastrous California earthquake of April 18, 1906, has been signalized by the formation of a Committee on Seismology of the American Association for the Advancement of Science; which committee, like its British cousin, is composed of fifteen members. The gentlemen selected, who represent all sections of the country, and the more important institutions likely to be engaged in seismological research, are as follows: L. A. Bauer, Carnegie Institution; W. W. Campbell, Lick Observatory; C. E. Dutton, U. S. Army, Washington, D. C.; G. K. Gilbert, U. S. Geological Survey; J. F. Hayford, U. S. Coast and Geodetic Survey; W. H. Hobbs, University of Michigan; L. M. Hoskins, Stanford University; T. A. Jaggar, Massachusetts Institute of Technology; Otto Klotz, Ottawa Observatory;

A. C. Lawson, University of California; C. F. Martin, U. S. Weather Bureau; W J McGee, St. Louis Public Museum; H. F. Reid, Johns Hopkins University; C. J. Rockwood, Jr., Princeton University; and R. S. Tarr, Cornell University. In the preliminary organization of the committee Dr. G. K. Gilbert was chosen chairman and Dr. W. H. Hobbs, secretary.

Some of the objects in view in forming the committee on seismology in America are as follows:

1. To be available for, and to initiate counsel in connection with, legislation which provides for investigation of earthquakes or the means for mitigating their dangers.

2. To bring into harmony all American and Canadian institutions doing seismological work, and to guard against unnecessary duplication of studies.

3. To organize, if thought best, a correlated system of earthquake stations, which should include the outlying possessions and protectorates.

4. To advise regarding the best type or types of seismometers for the correlated stations.

5. To disseminate information regarding construction suited to earthquake districts.

6. To collect data regarding the light as well as the heavy shocks, and to put the results upon record.

7. To start investigations upon large problems of seismology.

8. To advise with some weight of authority when catastrophic earthquakes have wrought national calamity.

An additional object of the committee's conferences has been suggested by the latest disaster in Jamaica. Press notices, presumably correct, call attention to marked changes of soundings within the harbor of Kingston as a result of the earthquake; and the interruptions of the Bermuda and Panama cables probably register larger movements along the scarps bordering the great deeps. The region as a whole (and the harbor of Kingston in particular) is one within which particularly accurate soundings have been made. A resurvey as early as is practicable will probably yield valuable data regarding the nature of under-sea changes at the time of earthquakes. There is probably today no portion of the field of seismological research so little exploited, and yet so full of promise, as the study of data already in the possession of telegraphic cable companies. The little already accomplished by Milne has demonstrated both the value of these data

and the reluctance with which the cable companies consent to part with them. The committee should see whether, either alone or in co-operation with the British committee, something may not be accomplished in securing access to these valuable data. If the companies could be made to see that studies by the committee are likely to serve them in suggesting better methods of meeting their special difficulties, much might be gained.

Almost at the same time that the American Committee on Seismology was founded there was organized upon the Pacific coast the Seismological Society of America. Though the name is as broad as the continent, the composition of the Board of Directors and the Scientific Committee indicates that the field of the society's endeavors is to be the Pacific states. The president of the society is George Davidson, and the secretary George D. Lauderbach. The chairman of the Scientific Committee is Professor Andrew C. Lawson, who is also first vice-president of the Board of Directors. The other members of the Scientific Committee are J. C. Branner, G. K. Gilbert, C. Derleth, Jr., J. U. Le Conte, A. S. McAide, and H. F. Reid. Membership in the society is fixed at $2 per year for ordinary membership and $25 for life membership. It is announced that a regular publication is one of the objects of the society. An American journal of seismology would do much to develop the latent interest in the subject, and it is to be hoped that one will soon be launched.

There is another movement, less in evidence as yet, but hardly less certain to arrive. Several American universities following the example of Johns Hopkins, are now making plans for the equipment of an earthquake station, and close upon these installations is sure to follow a new emphasis placed upon seismology as a part of a geologist's training. The chair in seismology founded in the University of Tokyo in 1886, and occupied successively by the distinguished seismologists Sekiya and Omori, is today unique in the world; and, with the exception of an unsuccessful course in seismology given years ago at the Sorbonne, the branch has not been dignified as yet by separate treatment in the university curriculum. A beginning has just been made at the University of Michigan, where in the winter semester of 1906–7 a lecture course upon seismic geology has been given two hours each week. W. H. H.

Under the civil polity of the United States, certain functions which relate to the welfare of the whole nation are assigned to the national government, while other functions of more circumscribed bearings are reserved to the states. The principles which underlie this polity are as applicable to the scientific functions of the government as to any other. Those inquiries which bear upon the common welfare, irrespective of state limits, fall within the sphere of the national investigative organizations; those which relate to local interests belong to the province of the state scientific organizations, or to those instituted by municipal or other sub-state governments. It is obviously easier to state this basis of division than to apply it; for few scientific inquiries are so local as not to benefit the whole nation, directly or indirectly, and few are so general that they do not affect the welfare of the people of one state more than those of others.

None the less, if these general principles are clearly apprehended and kept steadily in mind, a working system in reasonable accord with them can be established and maintained in the scientific field, as it has been for more than a century in the political. It is clear that those problems which are embodied in the phenomena of more than one state in such a way that the investigations necessary for their solution must be pursued in neglect of state lines, fall within the functions of the national organization; while those which lie wholly within state limits, and do not bear trenchantly on any fundamental or general problem, as clearly fall within the functions reserved to the states respectively. Into the one or the other of these two great classes fall no small part of the geological problems of the domain belonging jointly to the nation and the states, and these may be easily distinguished in practice. Until we change our system of government, the national survey should not undertake the latter class of problems, nor the states the former. The intermediate class of problems, not so clearly defined, are to be compassed by co-operation and mutual agreement.

If these considerations are true and just, it is clear that every state has a scientific function to perform; for no state government is true to the interests of its people, in this stage of human evolution, that does not care for the intellectual as well as the political welfare of its

people, and scientific inquiry is fundamental to the intellectual development of every progressive people.

We hold, therefore, that no state is doing its duty to its people, or its part as a factor in our governmental system, which does not maintain a well-organized system of scientific investigation covering the essential physical conditions and the potential resources that relate to the health, prosperity, and happiness of its people. Among these we naturally place a geological survey. A state is shirking its duty and its responsibility, if it leaves all this investigative work to the national government. It is not right for the national government to do it all, as functions are now apportioned. Let every state, therefore, do its part zealously. Let the national government do its part, but only its part. A spirited endeavor by each to fulfil its functions, attended by a generous co-operation when the dividing line between functions is obscure or debatable, will develop and preserve, in the scientific field, that community of action in promoting the higher welfare of our people which is the soul of our civil polity.

T. C. C.

REVIEWS

Structural and Field Geology. By JAMES GEIKIE. New York: S. Van Nostrand Co. Pp. xx+435, 56 full-page plates, 142 illustrations in text.

The student whom Mr. Geikie seems to have had most prominently in mind, during the preparation of this work, is the prospective mining engineer. The book is an excellent handbook for those wishing to make some practical use of geology or to study the science from a practical standpoint.

The first five chapters deal with rock-forming minerals and rocks. In chap. vi the modes of preservation of organic remains in rocks are described, and the significance of fossils in geologic studies is briefly pointed out. Chap. vii treats of stratification, and chap. viii of concretionary and secretionary structures. There then follows a full and well-illustrated description, occupying the next four chapters, of the structures common to sedimentary rocks. The mode of occurrence and the structural relationships of eruptive rocks are treated in chaps. xiii and xiv. After the student has a knowledge of the chief materials of the earth, of the aggregation of these materials in the common rock formations, and of the attitudes and relationships of these formations, he is invited to consider the alteration and metamorphism of such materials and formations. Chap. xv is devoted to the consideration of such changes. In chaps. xvi and xvii ore formations are carefully figured and described.

The next three chapters, xviii–xx inclusive, are devoted to geological surveying, and chap. xxi to the preparation of geologic maps and sections. These four chapters include numerous practical suggestions on field equipment, field methods of work, devices for keeping notes on maps, etc.; they are addressed to beginners in field-work, and to them should prove very valuable. Chaps. xxii and xxiii deal with some economic aspects of geological structures. They include such topics as: the search for coal, conditions under which coal occurs, the search for ores, general considerations which should guide the prospector, geological structure and engineering operations, reservoirs, underground water, springs, common artesian wells, and the distribution of disease in relation to geological conditions. Soils and subsoils are the subject-matter for chap. xxiv and the

closing chapter, xxv, is devoted to a study of the relation of surface features to geologic structures.

Throughout the volume Mr. Geikie has limited himself to the more settled doctrines and principles of working geology, and has not attempted to present alternative views or possible objections. He has avoided the presentation of many of the problems now engaging the attention of structural geologists.

The photographic illustrations deserve special mention for their excellence, and among them the photographs of rock specimens are the most remarkable.

W. W. Atwood

The Viscous vs. the Granular Theory of Glacial Motion. By Oswin W. Willcox. Long Branch, N. J.: Published by the author, 1906. Pp. 23.

This is less a treatment of the theme implied by the title than a review of a particular statement of one phase of the granular theory.[1] Even as a special criticism it goes wide of the mark, as the author, inadvertently it is to be assumed, substitutes easily demolished propositions of his own for those of the sponsors of the granular theory. As the leading feature of his discussion, Dr. Willcox attributes to the special sponsor he selects the unlimited proposition that "strictly crystalline minerals are incapable of manifesting viscous fluidity," whereas the real proposition is the very special one that "the retention of *its* crystalline structure," by the *ice granule*, during glacial *motion*, is incompatible with a *viscous flowage* of the granule. The "universal principle" thus substituted for the special proposition is attacked by the citation of the peculiar phenomena manifested by certain organic compounds, called, with more or less questionable propriety, "crystalline liquids" and "liquid crystals." These interesting phenomena have been all along known to some of the sponsors of the granular theory, presumably to all, and have awakened the question whether these "liquid crystals" are not short of being *typical liquids* to the extent that they are "crystalline," and short of being *typically "crystalline"* to the extent that they are liquids. The more vital question, however, is whether or not they *retain* their "crystalline" character while undergoing continuous and protracted motion under stress. Had these questions been sharply discussed, with full and critical data, the contribution would have been at least suggestive as to theoretical possibilities of beha-

[1] Chamberlin, *A Contribution to the Theory of Glacial Motion*, University of Chicago Press, 1904.

vior in ice granules, but it would not have touched the real question how they actually behave. Nothing truer can be said of this academic discussion of a universal proposition substituted for a concrete and special one, than is said by the author in another part of his paper, where the aspect of his discussion is reversed: "But the laws of nature, considered apart from their special modes of action, have little interest or value in either theory or practice."

By way of showing how concrete and special the real propositions involved in the granular theory are, they may be put as follows:

I. Glaciers are formed of individual crystalline granules. II. These are controlled by a strong crystalline force. III. They are, however, subject to growth and decadence, resulting in the extinction of some crystals and the enlargement of others, and in changes of relations to one another. IV. The crystals of any part seem to be the enlarged or reduced descendants of those in the part above. V. Collectively they persist throughout the whole glacial movement, and individually they seem to persist through some notable part of it, at least. VI. They participate in the changes of form and the changes of attitude involved in the glacial movement. Now:

1. If the granules are deformed by a viscous movement within themselves, they should show the fact by the recognized characteristics of viscous deformation and flowage.

2. If the granules are deformed by fracture and regelation, they should show the characteristics of this action.

3. If they are deformed by the sliding of the gliding plates of the crystals over one another, they should show this.

4. If they retain their crystalline integrity, save for additions and losses, they should show this.

These are very definite, concrete alternatives, to be settled by studies on the actual phenomena of glaciers, and in no other way. The incompatibility of the last with the first is the specific incompatibility urged, not the universal incompatibility of all kinds of crystallinity with all kinds of viscosity.

No evidence of the first is known to the reviewer; the second is manifested locally; the third seems to have an important place under special conditions of stress; while the fourth seems to be abundantly evidenced by the characters and attitudes of the granules. Dr. Willcox is a young chemist, with a geological penchant, whose lack of personal familiarity with the intimate structure of glaciers does not permit him to discuss these propositions on the only basis that is entitled to weigh—that of observation.

In the latter part of the paper he questions the adequacy of the energy available for glacial movement. Instead, however, of following carefully the postulates of the granular theory, he substitutes postulates of his own which any advocate of the theory would repudiate. For example, instead of trying to estimate the value of the gravitative pressure and the insolation, direct and indirect, which are the sources of the energy of movement assigned by the sponsors of the theory, he discusses the value of the *impact* of the moving granules, and seems seriously to regard the energy represented by the velocity of the granules as the total energy available!

Preliminary to an effort to show that there are narrow limits to the possibilities of glacial advance under the granular theory, the author says: "According to this theory, as it is stated by its sponsors, the elongation of a glacier is due primarily to the relief from compression afforded by the intergranular spaces;" and on this basis he proceeds to discuss the limits of the compression of the granules and the insufficiency of the intergranular spaces. His special sponsor for the theory, however, says, after detailed exposition: "These considerations lead to the view that movement takes place by the minute individual movements of the grains upon one another." It is difficult to find an excuse or palliation for such substitutions of propositions, indefensible on their face, for the propositions actually advanced by the sponsors of the granular theory. If a subject so infelicitous for academic treatment as the minute dynamics of glaciers is chosen at all, it is natural to expect it to be treated with academic fidelity.

T. C. C.

THE
JOURNAL OF GEOLOGY

APRIL–MAY, 1907

REPORT OF A SPECIAL COMMITTEE ON THE CORRELATION OF THE PRE-CAMBRIAN ROCKS OF THE ADIRONDACK MOUNTAINS, THE "ORIGINAL LAURENTIAN AREA" OF CANADA, AND EASTERN ONTARIO

To C. Willard Hayes, Charles R. Van Hise, Albert P. Low and Frank D. Adams, General International Committee on Geological Nomenclature, Representing the Geological Surveys of the United States and Canada:

I. INTRODUCTION

At a meeting of the International Committee on Geological Nomenclature, representing the Geological Surveys of the United States and Canada, held at Ottawa, Canada, on December 31, 1905, it was decided that the subcommittee on the correlation of the pre-Cambrian rocks of the Adirondack Mountains, the original Laurentian area and of eastern Ontario, consisting of President C. R. Van Hise and Professor Frank D. Adams, which had been appointed at the first meeting of the committee, held in Washington on January 2, 1903, should be enlarged by the addition of Professor A. P. Coleman and Professor J. F. Kemp, and that Dr. J. M. Clarke, State Geologist of New York, should be invited to appoint a representative on this committee. Dr. Clarke was subsequently consulted, and appointed Professor H. P. Cushing as representative of the Geological Survey of the State of New York. Dr. Robert Bell was also invited to join the subcommittee. On July 4, when the committee assembled to begin its work, Dr. Bell, being in Europe, was unable to take part

in the work of the committee, and his place was taken by Dr. A. E. Barlow, of the Geological Survey of Canada. Dr. Barlow, however, was able to remain in the field only during a period of about ten days when the committee was at work in the Adirondack Mountains.

Dr. A. W. Spencer, of the United States Geological Survey, accompanied the committee from July 6 to July 23.

This special committee met at Whitehall, N. Y., on July 4, and spent the month of July, 1906, in visiting various districts in the Adirondack Mountains and in the eastern portion of Ontario, with the view of ascertaining, if possible, whether they could agree upon the succession and correlation of the great exposures of pre-Cambrian rocks in these areas, and also upon the nomenclature which should be adopted in the classification of the same.

The mapping of the eastern Adirondack area is now being carried on by J. F. Kemp, and that of the northern Adirondack area by H. P. Cushing and C. H. Smyth, but this work is not as yet completed.

The area visited by the committee in Canada was for the most part that whose mapping has just been completed by F. D. Adams and A. E. Barlow, and which is comprised in the Haliburton and Bancroft sheets of the Ontario series of geological maps being issued by the Geological Survey of Canada, printed copies of the maps in question being supplied to the members of the committee when in the field. The geological report on this area, however, has not as yet been published.

The committee also visited, while in Canada, the Madoc region, which lies to the south and southeast of the area mapped by F. D. Adams and A. E. Barlow. This area was in the early years of the Canadian Survey mapped by Mr. H. G. Vennor, and a portion of it was at a later date mapped on a larger scale by Mr. Eugene Coste.

In making the present report, therefore, the committee wish it to be distinctly understood that in it they are not presenting any new observations made by them in the areas visited, but are merely recording certain facts pointed out to them by Dr. Kemp and Dr. Cushing in the Adirondack area, and by Dr. Adams in eastern Ontario, which will be described in detail in the forthcoming reports by these several gentlemen. To the interpretation of these facts by the gentlemen in question the committee give their full assent, and upon them

base their recommendations for the correlation of these rocks in the several areas under discussion.

II. ITINERARY OF THE COMMITTEE

A. ITINERARY IN THE EASTERN ADIRONDACKS

(Under the guidance of J. F. Kemp)

The committee was summoned to meet in Whitehall, N. Y., on the night of July 4. The first week was devoted to areas which had been mapped by J. F. Kemp in or near the Champlain valley. July 5 the committee, represented by Messrs. Adams and Kemp, reviewed first the green syenitic gneiss in the southwestern portion of Whitehall village, where a massive eruptive rock has become so granulated and platy from crushing and shearing that it strongly resembles sandstone and is quarried like a stratified sediment. Next in the railway cuts north of Comstocks, garnetiferous, thinly foliated, micaceous gneiss was seen, which is believed to be sedimentary. The gneiss was penetrated both by red granite, now rolled out into thinly foliated gneiss with many leaves of quartz, and by a stock or small laccolith of gabbro, which had produced extraordinary rolls in the foliation. Two miles south of Comstocks and just east of the canal two strata of white, crystalline limestone were exposed, of which the lower is seventy-five feet thick, the upper much less. The limestones are associated with black hornblendic gneisses and with granitic gneisses of whose nature, whether sedimentary or igneous, it was not possible to positively decide. From their mineralogical composition they might be either, but the almost constant association with the limestones throughout the area creates a presumption in favor of sediments. The limestone exhibited interesting results of dynamic effects, in dragged and squeezed inclusions of hornblendic schist. In the area between the limestones and Comstocks was the basal Potsdam in a thin coat over the gneiss.

The following day Messrs. Coleman, Cushing, and Spencer joined the others in Whitehall, and all proceeded by the north road across the neck between Lake Champlain and South Bay. The party observed the syenitic gneiss which is believed to penetrate the rusty and somewhat calcareous sedimentary gneisses, and were impressed with the faulted nature of the topography. Crossing

South Bay they traversed platy quartzose, garnetiferous, sedimentary gneisses, with intrusions of gabbro and trap dikes. They observed in the gneiss a development of graphitic schist which has been mined. Proceeding several miles up Pike Brook, the party crossed an outlier of Potsdam sandstone faulted down between the hills of gneiss, and to the southwest on the old State Road saw a ledge of about forty feet of graphitic schist capped by gabbro. Returning, they recrossed South Bay and went over the high ridge to Whitehall, crossing doubtful gneisses, believed, however, to be probably sedimentary. The same evening the party moved to Ticonderoga.

From Ticonderoga, on the following morning, the committee proceeded to Hague on Lake George, and visited the Lakeside graphite mine, where a graphitic quartzite six to ten feet thick is inclosed in garnetiferous, sillimanite gneiss. Still lower are gneisses of quartzose, feldspathic composition. The party then rowed to Flirtation Island, north of Hague, where a gneiss which closely resembles a conglomerate was finally interpreted as one injected with pegmatite stringers and subsequently squeezed. Farther north at Indian Kettles Point a massive, garnetiferous granitic gneiss was seen which was believed to be intrusive. Returning to Hague, the steamer was taken to Rogers Rock, and the party climbed Rogers Slide, a summit about 850 feet above the lake. They crossed much white crystalline limestone, charged with silicates, graphitic pegmatites, and rusty gneisses, until toward the summit they passed to decidedly massive garnetiferous granitic gneiss, similar to the exposures on Indian Kettles Point. All were impressed with its igneous affinities, and attributed the garnets to the influence and contributions of the neighboring limestones. The rock is believed by J. F. Kemp to be an acidic phase of the syenitic eruptives which are normal and abundant in the vicinity. Proceeding to Ticonderoga on foot, the party traversed typical green syenite at the outlet of Lake George, and had no doubt of its eruptive nature.

The next morning the party moved to Port Henry and walked north on the tracks of the railway on the shores of Lake Champlain. Passing across faulted blocks of Beekmantown and perhaps upper Potsdam, they encountered a large intrusion of gabbro. At first gneissoid on the south, the gabbro passes gradually into more massive

phases until it is coarsely diabasic in texture. The gabbro is succeeded by a thick ledge of white crystalline limestone, into which it tongues out with various small apophyses. The limestone is charged with streaks and bunches of silicates, which are contorted in so extreme a degree as to give truly remarkable results of pressure. Farther north quartzose gneisses and more gneissoid gabbro were traversed, the former greatly brecciated by faulting. From the railway the party climbed the hill to the old Cheever magnetite mine and its northward extension. The ore is found as an extended bed, sometimes double, and a half mile or more in length. It is contained in a gneiss, of granitic composition, which has gabbro a short distance below and white crystalline limestone a short distance above. Various opinions were advanced about the nature of the gneiss and the origin of the ore, sedimentary, intrusive, and contact views being all expressed without reaching unanimity. Returning by highway to Port Henry, the party visited the ophicalcite and white limestone quarries lying to the west of the road, and saw the latter rock much cut up by pinched pegmatites and basic stringers.

The following day the committee drove to Mineville, six miles northwest, and on the way visited another quarry in white limestone and the abandoned Pilfershire magnetite mines. The relations of the ore are much the same as at the Cheever, except that heavy drift so masks the exposures below the gneiss forming the wall-rock that their nature cannot be told. At Mineville the party visited the great iron mines and studied the relations with the overlying acidic gneiss and the underlying, generally basic, hornblendic variety. At the belt of ore on Barton Hill it was shown that the underlying hornblendic gneiss passed directly into gabbro. Various views were suggested for the formation of the ore, some favoring igneous segregation, others contact metamorphism, still others replacement or sedimentation; but the problem was too obscure for agreement. In the evening the party was joined by C. R. Van Hise and A. E. Barlow.

The following day the committee again went over the mines and examined the maps which were courteously shown by the chief engineer of the company, and later visited the outlying workings at Cook Shaft and Fisher Hill. The general feeling was that several successive processes might have been involved in producing the ore

in its present form. In the evening all moved to Plattsburg, where H. P. Cushing became the guide.

In the eastern Adirondacks the attempt was made to visit the rocks of actual or probable sedimentary character, rather than the great eruptives of whose nature there is much more certainty.

B. ITINERARY IN THE NORTHERN ADIRONDACKS

(Under the guidance of H. P. CUSHING)

On July 11 the party went from Plattsburg to Tupper Lake, with stops at Dannemora and Saranac. At Dannemora amphibolites were seen, cut by granitic gneisses, and both cut by unmetamorphosed dikes of diabase and syenite porphyry. The locality was typical of a great area in the northern Adirondacks where such a gneiss complex prevails, along with frequent gray gneiss of intermediate composition. The origin of the amphibolite is uncertain. The complex has been called the Saranac gneiss and is precisely like that seen later in many places in Canada.

At Saranac a locality was visited which showed irruptive contact of anorthosite with gneisses which, while themselves of somewhat doubtful nature, are in close association with undoubted Grenville sediments near at hand.

The following day the party drove from Tupper Lake to and through Litchfield Park, seeing the gradation from the typical green syenite along the lake to the reddish, granitic phase of the same rock in the park, and seeing also the red granites, almost wholly quartz-feldspar rocks, which cut the syenite. A small anorthosite outlier was also visited. This is surrounded on all sides by the red syenite, which, as the anorthosite is neared, grades into a basic green syenite which cuts the anorthosite, though the best locality for seeing this was not located. Adams did not accompany the party on this day.

July 13 the committee drove from Tupper Lake to Axton, seeing first green syenite, followed after an interval with no exposures by anorthosite cut up by dikes of varying sizes of a rock which H. P. Cushing believes to be the syenite, and which seemed such to the other members of the party except A. W. Spencer, who expressed some doubt as to the equivalence. Beyond, the route was entirely

in anorthosite, of somewhat gabbroic nature for the most part. Panther Mountain, at the south end of Upper Saranac Lake, which was climbed by the party because of the good view of the general topography of the region obtainable from its summit, furnished a good exhibition of the general character of the anorthosite. Syenite dikes of various sizes persist in the anorthosite with diminishing frequency for a distance of three or four miles from the edge of the mass.

The next day boats were taken at Axton for a trip down the Raquette to Tupper Lake, with a side excursion into Follensby Pond. The anorthosite was found grading from the normal rock at Axton into a basic gabbro near Follensby Pond, adjoined by the syenite in somewhat basic phase, illustrating the general tendency of the anorthosite bathylith to become more basic at its borders, and the similar tendency of the syenite to become more basic in the vicinity of the anorthosite. At the upper end of Follensby Pond Grenville rocks were seen, the outcrops being at the northern extremity of a long belt of these rocks extending unbroken for several miles. Limestone, both pure and impure, rusty graphitic gneiss, and a little quartzite were seen. These and other rocks of the belt are precisely like those seen the preceding week and those seen later in Canada. Down the river from Follensby the rocks seen were anorthosite of the gabbro type followed by syenite.

The rocks of the central area of the Adirondack region consist mainly of bathyliths and smaller masses of anorthosite, syenite, granite, and gabbro, with only occasional patches of the sediments, and the region seen in the three days was a good sample of the general area. The asymmetric differentiation of the syenite into a basic type in the vicinity of the anorthosite, which it cuts, and into an acid type in the contrary direction where it adjoins and cuts granitic gneisses, as well as the local differentiation of the acid syenite into the basic type around an inclusion of anorthosite, seemed to point to the digestion of material from the adjacent rocks as a cause of the differentiation.

Monday, July 16, was mainly taken up in journeying from Tupper Lake to Theresa in Jefferson County, to see there the rocks as they appear in the northwestern region. The evening of July 16 and the whole of the next day were spent in this examination. A thick

limestone formation was seen, and a great thickness of other rocks in thinner beds, including limestones, quartzites, amphibolites, and various gneisses, all of which were cut by dikes and small bosses of granite. The series seems to be sharply folded—so sharply that the prevailing dips are in one direction. The thick limestone was found to be overlain by a great mass of granitic gneiss, under which it seemed to dip, and with no sign of contact action in the limestone, though there were traces of it in the edge of the granite. Some varieties of gneiss somewhat suggest tuffs. The Potsdam is just being worn away from the pre-Cambrian with many patches of it, both large and small, yet in position, showing various conglomerates and a very irregular deposition floor. Near at hand, but not visited, is a large granite bathylith full of amphibolite inclusions, precisely like those seen later near Deloro and Gooderham.

In the evening the party went to Clayton.

C. ITINERARY IN EASTERN ONTARIO

(Under the guidance of F. D. ADAMS)

The committee then crossed the St. Lawrence into Canada, taking the ferry from Clayton to Kingston, from which latter place they went by train to Tweed.

From here they proceeded to Bridgewater, in order to examine certain conglomerates referred to by Vennor. About half a mile east of Bridgewater they found granite protruding through the drift, which granite was succeeded immediately to the west by a body of amphibolite. In the amphibolite an autoclastic structure was developed in places, which gave rise to an appearance faintly simulating a conglomerate. All the members of the committee, however, agreed that this structure was autoclastic and was of no stratigraphical significance.

Passing by a great development of crystalline limestone with interstratified bands of fine-grained gneissic rocks at the village of Bridgewater, the committee went to a point one and a half miles west of this village, where they found exposed by the side of the road a conglomerate which is undoubtedly of true clastic origin.

This conglomerate is exposed for several miles along the Madoc road, which runs east and west, and a good cross-section of the

conglomerate and the strata with which it is associated was found on the Queensboro road, which crosses the Madoc road at right angles. The conglomerate contains very numerous pebbles of several different kinds of rock. These are as follows:

1. Pink felsite. These are most abundant and form the dominant element of the conglomerate.

2. White quartz, resembling vein quartz.

3. White quartzite.

4. Amphibolite, dark in color and very fine in grain.

To the west of the Queensboro road the conglomerate also holds some pebbles of cherty and ferruginous rocks resembling those found in the iron ranges of the Lake Superior district.

The pebbles of this conglomerate are often quite round, but are usually very considerably flattened. They are sometimes several inches in diameter. The rock shows very considerable variations in size and abundance of the pebbles in different bands, some bands being entirely free from pebbles and resembling a quartzite in appearance. The conglomerate also shows distinct cross-bedding in certain places. It has a nearly vertical attitude, its beds being bent back upon themselves in a series of sharp folds.

On the Queensboro road, to the south of its intersection with the Madoc road, the conglomerate is followed by a dark amphibolite containing a great number of small corrugated quartz veins, presenting a remarkable autoclastic structure and often pinched out into forms closely resembling pebbles. This is succeeded by a series of pink felsites, which in their turn are followed by calcareous amphibolites, and these by crystalline limestones.

The succession on the Queensboro road from north to south, with the approximate thickness of the several occurrences (as exposed), is as follows:

Dark amphibolite, for the most part massive	600 feet +
Conglomerate (probably duplicated by folding)	3,100 "
Amphibolite with quartz veins showing autoclastic structure	?
Pink felsites	352 "
Calcareous amphibolite	935 "
Crystalline limestone	300 " +

Before the conglomerate was laid down it is certain that the

crystalline limestone, the calcareous amphibolite, and the pink felsites were in a condition to yield fragments, that such fragments were well rounded by water action, and that these formations were the chief sources of material for the conglomerate. It therefore follows that there is an important local break between the conglomerate and the underlying formations. However, the district is one in which contemporaneous volcanic action occurred, and when the conglomerate is traced along the strike it appears to contain volcanic clastic material. The question therefore arises whether this conglomerate marks a general uncomformity in the sedimentary series for the district or is a local unconformity. This question can be finally decided only when the Madoc district is mapped in detail.

The committee then went to Deloro, which lies about seven miles to the west of the village of Madoc. In this vicinity they found a large mass of granite, constituting what is locally termed the "Huckleberry Rocks," penetrating a series of highly altered impure crystalline limestones and developing in the latter a great variety of silicates in the form of irregular bands and masses.

A short distance to the north of the village of Deloro the granite was found cutting a dark amphibolite, of which it inclosed an immense number of angular fragments which in places presented distinct evidence of being absorbed by the granite mass. It was not quite clear whether this process of absorption was produced by the complete solution of the amphibolite in the granite and the subsequent recrystallization of the resulting mass, or whether the intermediate rock had resulted from a very complete penetration of the intruded amphibolite by granitic material. According to Mr. Coste, the amphibolite in question results from the alteration of the limestone by the granite mass, but the limited time at the disposal of the committee did not permit them to examine a sufficient area to enable them to satisfy themselves on this point. Some of the amphibolitic masses included in the granite, however, had the appearance of tufaceous material—a fact which is of importance in connection with the question of the origin of the amphibolite as a whole. The committee considers that this granite intrusion presents one of the finest known examples of both exomorphic and endomorphic contact action.

The committee then went north to the village of Bannockburn, about a mile to the southwest of which, on the road, they found a great body of massive diorite or amphibolite in contact with the same limestone series, the two rocks being folded together along their contact. The appearance of this dioritic mass near Bannockburn suggests somewhat, in the traces of ellipsoidal structure which it presents, certain Keewatin rocks of the Lake Superior region.

The committee then visited the district about Millbridge on the Hastings road, where they again found the same limestone series which here, being very free from igneous intrusions, is comparatively unaltered in character and preserves its original blue color. This body of limestone, however, although apparently uniform in character, is seen, on a careful study, especially of the weathered surface to contain many thin, interstratified layers which are much harder than the limestone itself, and which when examined under the microscope are found to be composed almost entirely of silicates, chiefly feldspars, both plagioclase and orthoclase, with quartz and some biotite. The rock composing these layers now shows a perfect "pflaster" or pavement structure, and is completely crystalline. It is, however, of undoubtedly sedimentary origin and has been referred to by Adams as "paragneiss". These bands are of importance as representing in this comparatively unaltered portion of the limestone formation rocks which, when the alteration of the formation is more pronounced, assume a much more distinctive form.

From Millbridge the committee went north on the Hastings road, which, running at right angles to the strike of the rocks, affords a most admirable section through the sedimentary series with its various interstratified rocks, for a distance of thirty miles north of Millbridge, where the sedimentary series becomes torn to pieces by the great invasions of the granite bathyliths to be mentioned later.

About three miles to the north of Millbridge a great intrusion of more or less altered gabbro, about two miles in width, was crossed. This was found to be nearly massive in character and to alter the intruded sedimentary rocks.

Crossing over this intrusion, the limestone series was again encountered, the Hastings road for the next six miles passing over more or less continuous exposures of limestone, interstratified in places

with a considerable volume of bedded amphibolites and fine-grained gneissic rocks which either represent intercalations of muddy sediments analogous to those forming the paragneisses about Millbridge, or have originated from the complete alteration of volcanic ashes which fell into the sea at certain times during the deposition of the limestones. The chemical composition of the majority of these amphibolites is such that they might be derived either from the alteration of calcareous silts or from showers of basic volcanic ashes. The existence of numerous gabbro intrusions, having a more or less rounded outline, in association with this limestone series, more especially where these amphibolite bands are abundant in it, suggests that these represent the bases of volcanic centers from the ejectamenta of which the amphibolites were derived.

Having gone north on the Hastings road as far as Murphy's Corners, the committee then proceeded to Gilmour, a station on the Central Ontario Railway about five miles to the east of the Hastings road, to examine certain conglomerates which are found in that vicinity associated with two bodies of granite which penetrate the limestone series.

The committee considered these conglomerates to be in part of autoclastic origin, and, in all probability, in part of volcanic origin, representing tufaceous material derived from volcanic centers now represented by the masses of granite associated with it. Dr. Barlow, however, who mapped the occurrence, considers them to be of exclusively autoclastic origin. The time at its disposal did not enable the committee to make a detailed examination of the stratigraphical relations of this conglomerate, but after the field-work of the committee was brought to a close, Messrs. Cushing and Adams returned to this locality and re-examined the conglomerates. They found that they were interstratified with limestones, and consequently of the same age as these rocks, and that, on approaching the granite mass lying to the east, these rocks were thrown into a series of very sharp folds, evidently due to their being pressed against the granite mass, and that the granite mass, immediately about its contact with these rocks, exerted a very pronounced exomorphic contact action, changing the limestones for a distance of at least 100 yards into a mass of reddish-green rock consisting of an admixture of epidote, garnet, pyroxene, and

other minerals. The committee therefore considers this conglomerate to be of interformational origin, and to have no special structural significance.

The committee then proceeded by train to Ormsby, where they examined a remarkable development of the limestone series consisting of beds of limestone interstratified with thin bands of amphibolite, displaying a series of very intricate folds. They also examined the Thanet gabbro, a large intrusive mass of approximately circular outline which here breaks through the limestone series, sending dykes into it and including masses of the latter. They also visited the Coehill iron mines, situated about five miles to the west of the village of Ormsby, where a very considerable body of somewhat pyritiferous magnetite is developed in the limestones, here interstratified with amphibolite about the contact of an intrusive mass of syenite.

Between Ormsby and Ormsby Junction the committee saw a great development of the typical rusty gneiss which is so commonly associated with the white crystalline limestones wherever these occur in the area embraced by the work of the committee. The development of these gneisses at this locality is one of the thickest which have hitherto been discovered in this series. Some bands of it resemble in appearance certain varieties of the Magnetite-Grunerite Schist of the Lake Superior iron ranges.

From Ormsby Junction the party went north by railway, passing over a further extension of the limestone series to Bancroft on the York branch of the Madawaska River, and examined the nepheline syenites, which have a very extended development in this district, and which in one locality about two miles and a half on the east of Bancroft are traversed by veins containing large masses of sodalite which are now being worked for decorative purposes.

They then went east to Bronson's Landing and proceeded by canoes down the York branch of the Madawaska to Craigmont, and spent three days in examining the very extensive and highly interesting occurrences of corundum which are here being mined on an extensive scale. This corundum occurs in syenites, most of which are rich in nepheline.

The party then returned to Bancroft and went by the Irondale, Bancroft & Ottawa Railway to Gooderham, stopping on the way to

examine a large deposit of biotite, formerly worked at this point, and which occurs in a granular, green pyroxenite which represents an altered limestone, near Wilberforce station. The limestone band is here highly altered, owing to the fact that it lies between two great bathyliths of granite.

At Gooderham the committee studied the relation of the limestone series to one of the great bathylith intrusions which form the northern portion of the area mapped by F. D. Adams and A. E. Barlow. This, which is known as the Glamorgan bathylith, is here ten miles wide and is completely surrounded by the limestone series through which it breaks. They first examined the eastern margin of the bathylith. Starting from the normal development of the limestone series on the line between the townships of Glamorgan and Monmouth, they went westward toward the bathylith, following the Ursa road. They found the limestone series became penetrated by dykes of granite in ever-increasing numbers, becoming eventually torn into fragments which lay thickly scattered in the granite forming the margin of the bathylith. It was noted that the limestone on going toward the granite became progressively more impure, being apparently replaced by amphibolite, and that but few fragments of limestone could be found among the inclusions of the granite itself.

The committee then examined the southern contact of the bathylith in the railway cutting at Maxwell's Crossing on the Irondale, Bancroft & Ottawa Railway. Here they found undoubted evidence that the limestone was being changed by the granite, first into a rock composed of pyroxene, plagioclase feldspar, scapolite, and calcite, and then, when the action was more intense, by a further change into a gray amphibolite consisting of hornblende, pyroxene, and feldspar, the latter dominantly plagioclase. The committee are of the opinion that the evidence is indisputable that the granite bathyliths in this region change the invaded limestone into a dark-gray amphibolite, which, together with the fragments of the interbanded amphibolites found everywhere in the limestone series, occurs scattered throughout the granite mass in the form of included fragments. By this statement it is not meant to imply that all of the amphibolites of the district are derived from the metamorphism of limestones, for in some places the amphibolites appear to be metamorphosed

pyroclastic material, and in other places they originate from the metamorphism of intrusive basic igneous rocks. One of the chief difficulties solved in the study of the district by Adams was the recognition of the fact that the amphibolites had such diverse origins.

In the vicinity of Gooderham the committee also examined a large occurrence of titaniferous iron ore representing a differentiation product of a large gabbro intrusion which occurs to the south of Gooderham. This iron ore is situated on lot 35 of Range IV of the township of Glamorgan. They also saw several occurrences of graphite in the limestone series in this vicinity and examined three occurrences of nepheline syenite which are here found penetrating the limestone series. These nepheline syenites hold in many places inclusions of calcite, often of microscopic dimensions, which are clearly fragments of the limestones in which the nepheline syenites occur.

Leaving Gooderham, the party went north across the entire width of the Glamorgan bathylith to Haliburton. They found the bathylithic mass to form an area of very rough country, unlike that underlain by the limestone series. They also found the bathylith to consist chiefly of a fine-grained reddish gneissic granite, very poor in iron magnesia constituents. This, however, contained almost everywhere numerous inclusions of several varieties of amphibolite which the committee believe can be clearly proved, as held by Adams and Barlow, to represent fragments of the invaded limestone series. In addition to these there are considerable bodies of a grayish gneiss, which are believed to represent amphibolite inclusions which have been entirely absorbed or dissolved by the granite magma. It was stated by Adams that throughout the whole great area to the north of the district examined by the committee the bathylithic masses of granite were filled with similar inclusions. He estimates that these bathyliths on an average consist of about 80 per cent. of the red granite, 10 per cent. of the gray gneiss, and 10 per cent. of amphibolite inclusions, resulting in the way above mentioned.

About Haliburton the committee found the limestone series appearing in great force, developed in some places as great cliffs of white marble. This limestone can be traced continuously around the east end of the bathylith to the Ursa road and to Maxwell's Crossing,

where the committee formerly examined it. To the north of Haliburton it is flanked by another bathylithic mass similar to that just described.

In this connection it should be remarked that, while the sedimentary rocks of this district have been referred to as the limestone series, this name has been adopted because in this series limestone is the dominant rock. The limestone is, however, commonly impure, not infrequently passing into phases in which the non-calcareous sediments are important or even dominant. Locally the sediments were apparently of the nature of altered volcanic fragmental material. This heterogeneity of original composition naturally leads to very great variety in the metamorphosed products, which vary from gneiss through calcareous schists to marbles and several varieties of amphibolites.

At Haliburton the field-work of the committee was brought to a close.

III. RÉSUMÉ OF THE GEOLOGY OF THE ADIRONDACK AREA

So far as known, the oldest series of rocks in the Adirondack area consists of strongly and coarsely crystalline limestones, ophicalcites, quartzites, quartz-schists, rusty, micaceous, thinly foliated gneisses and more massive gneisses. Among these the limestones are on the whole the ones most easily recognized. On the east they are well and prominently developed. In the central area they seem to be extensive, but are poorly exposed, and quartz schists are prominent. On the northwest they appear in largest amount and form continuous belts over long distances. The limestones are usually charged with bunches and streaks of silicates, which are in part torn and sheared intrusives, in part pegmatites, and probably also in part former siliceous, ferruginous, aluminous bands.

The quartzites on the east are best developed near South Bay, one of the two southern arms of Lake Champlain. They are thoroughly recrystallized, and all original clastic structure has been destroyed. They may contain great proportions of feldspar, and may also have sufficiently large percentages of graphite to be mined for this mineral. These feldspathic varieties were doubtless originally shales.

Rusty micaceous rocks with a peculiar yellow color on exposed surfaces are also frequent, although not in great thickness. They and other schistose, micaceous gneisses are believed to be recrystallized sediments.

Beneath the above, and sometimes interstratified with them, are more massive gneisses of a general granitic composition. While quartz and feldspar are the principal minerals, dark silicates also appear of the following kinds: emerald-green augite, brown hornblende, and biotite. Several varieties of gneiss are known depending on the relative proportions of these minerals. The iron ores are associated with them in almost all cases. It is a doubtful point as to whether these gneisses are in any cases sediments. They may be mashed, intrusive, granitic rocks in which the foliation is secondary, or they may be extreme phases in the metamorphism of arkoses or acidic volcanic tuffs.

In the Adirondack Mountains the series is invaded by enormous bodies of intrusive rock (anorthosite, gabbro, syenite, etc.), so that the sedimentary portion of the series forms a relatively smaller proportion of the whole complex than in the other areas covered by the work of the committee.

The undoubted sediments and their associated gneisses of uncertain origin are penetrated by several varieties of plutonic eruptives. The oldest constitute the anorthosite series, and embrace rocks from aggregates of nearly pure plagioclase to fairly rich mixtures of augite, hypersthene, and ilmenite with the plagioclase. The borders of the great bathyliths tend to be more basic than the centers.

The next in time among the intrusives constitute the syenite series. The typical rocks consist of microperthite, augite, hornblende, biotite, and varying amounts of quartz. Subordinate varieties are as rich in quartz as typical granites. Near the contacts with anorthosites and limestones garnets become numerous.

The third eruptive series consists of typical granites of both hornblendic and micaceous varieties. Areally the granites are of small extent, but they appear in scattered exposures outside the anorthosites.

The fourth series consists of dark basic gabbros, which are certainly later than the others, except perhaps the granites. No intersections with the latter are known. The basic gabbros appear in

wide distribution throughout the area, and form dikes, stocks, and small laccoliths.

All these intrusives preceded a great period of metamorphism. Following it and still antedating the Potsdam, there entered two series of narrow dikes: one of basaltic rocks, which are very widely distributed, and a minor set of syenite-porphyry.

The oldest Paleozoic sediment anywhere in the Adirondacks is the Potsdam sandstone.

From the above it is evident that in this area the pre-Cambrian formations are practically the same as those in the neighboring parts of Ontario and Quebec.

IV. RÉSUMÉ OF THE GEOLOGY OF THE EASTERN ONTARIO AREA

The area presents an immense development of highly metamorphosed rocks, for the most part of sedimentary origin. Among these limestones preponderate. These limestones in the southern portion of the area, where the metamorphism is less intense, are often fine in grain and drab or bluish in color. On going north, however, there is a progressive increase in the intensity of metamorphism, and the limestones gradually lose their color and become coarser in grain, eventually developing into coarsely crystalline white marbles, generally more or less impure.

Interstratified with these limestones are non-calcareous rocks, among which fine-grained, often more or less rusty weathering gneisses and a variety of amphibolites are the most important and the most abundant. A few bands of quartzite also occur, although in this area these are distinctly subordinate

These gneisses certainly represent highly altered and recrystallized sediments, more or less argillaceous in character. The quartzites are in the majority of instances altered arenaceous sediments. Adams has shown that the amphibolites have a threefold origin. Certain of them represent limestones which have been altered by invading granites; others have been produced by the dynamic alteration of basic igneous intrusions; while still others have in all probability resulted from the recrystallization of basic fragmental volcanic material. The remarkable fact is that all these processes produce amphibolites which cannot be distinguished from one another

either by appearance or by chemical analysis. The discovery of their genetic relations affords the key to the solution of some of the most important problems presented by this and other similar areas.

The relative abundance of the limestones and their associated gneisses and amphibolites varies from place to place. In some parts of the area there are enormous developments of nearly pure limestones. Elsewhere these are very impure, while in some places there are great thicknesses of amphibolites and gneisses entirely free from limestones.

The limestones with their interstratified and bedded amphibolites are usually steeply inclined, although in certain parts of the area they keep a nearly horizontal attitude.

The thickness of the series cannot be determined, but it is very great. It is one of the thickest pre-Cambrian series in North America.

Along its whole northern border this sedimentary series is torn to pieces by an enormous volume of gneissic granite of igneous origin which rises from beneath it, and which along its margin also wells up through it in the form of great intrusive bathyliths. This is filled with included fragments of the invaded series, limestones altered to amphibolites, fragments torn from interstratified bands of amphibolite, or of sedimentary gneiss, being scattered through it everywhere and being sometimes found in a more or less digested condition.

The base of the series has nowhere been found. Wherever its lower surface can be seen, it rests on great masses of the gneissic granite, which are intrusive into it and which, as has been mentioned, rise through it in the form of bathyliths.

In addition to the granite intrusions, around the border of which in many places there are occurrences of nepheline syenite which afford one of the most interesting studies in the area, there are also several larger and a number of smaller intrusions of a basic gabbro and gabbro-diorite. These often show a wide range of magmatic differentiation.

There are also a few smaller intrusions of anorthosite in the western part of the area, but these are distinctly subordinate.

A few small intrusions of typical granite also occur, one of which in the township of Lake, forms the center of a development of acidic lavas and apparently represents the plutonic plug of an ancient volcano.

Whether these intrusions of gabbro antedate those of the granite cannot be determined with certainty, as the two sets of occurrences are not found in contact.

In Logan's original examination of the southern portion of the area he used the designation "Hastings series" for the less altered portion of the series, and the term "Grenville" for the more highly altered portion. He expressed the opinion, however, at the time, that the Hastings series in all probability represented the Grenville series in a less highly altered form.

V. RÉSUMÉ OF THE GEOLOGY OF THE "ORIGINAL LAURENTAIN AREA" AND ITS EASTERLY CONTINUATION IN THE DISTRICT TO THE NORTH OF THE ISLAND OF MONTREAL

It has been thought well to make reference here to the "Original Laurentian area" and to its easterly continuation to the north of the island of Montreal. The committee did not examine these districts, but the former was studied by Sir William Logan in the early years of the Canadian Survey, a map of it having been published in the atlas accompanying the report of the survey for 1863, while the latter district was studied by F. D. Adams, his report and map of it appearing in 1896. As the studies in these districts have played an important part in shaping the nomenclature adopted in the case of the pre-Cambrian rocks of eastern America, the committee requested Dr. Adams to prepare the following brief description of them.

The "Original Laurentian area" of Logan lies in the province of Quebec, on the north shore of the Ottawa River, between the city of Montreal and the city of Ottawa, and takes its name from the township of Grenville and the village of that name, which lie within it. The second area mentioned forms the continuation of this "Original Laurentian area" to the east, and embraces the district about St. Jerome and eastward nearly as far as the St. Maurice River. There is every reason to believe that the area embraced by these two districts represents the continuation of the pre-Cambrian series studied by the committee in eastern Ontario, seeing that both occupy precisely the same relative position along the southern margin of the protaxis and that rocks similar to them in petrographical char-

acter occur in the intervening tract of country. In the development of these rocks in the province of Quebec, however, the "Hastings" facies (see p. 201) is absent, the rocks being all highly altered, and resembling in this way those found in the Adirondack Mountains and in the more altered portion of the Ontario district.

The "Original Laurentian area" and its easterly continuation above mentioned, like the area in eastern Ontario, occupy the southern portion of the Laurentian peneplain, underlying a great tract of slightly undulating country. They are composed of great bands of limestone interstratified with amphibolite and rusty weathering gneiss, often highly garnetiferous. This rusty weathering gneiss, where it occurs typically developed in the district about St. Jean de Matha, is found to be rich in sillimanite and to have the chemical composition of an ordinary clay slate. Bands of quartzite are also present in a number of localities, being interstratified with the gneisses and limestones above mentioned. Limestone, however, is the dominant rock of the sedimentary series.

In Logan's "Original Laurentian area" this distinctly sedimentary series occurs in great folds, the horizons marked by the limestone bands, as mapped by Logan, striking across the country in a series of great sweeping curves. The large bodies of orthoclase gneiss which are present in the district and which Logan considered to form part of the sedimentary series, a more detailed examination in view of recent discoveries would probably show to belong to the lower igneous gneisses and to be of intrusive origin.

Farther east, in the district to the north of the island of Montreal the limestone series is not always so sharply folded, and in one portion of the district, over an area of about 750 square miles, it lies nearly flat, low quaquaversal dips being everywhere observed, the attitude of the beds suggesting that the whole series originally floated on a great body of the underlying granite gneiss. This farther north comes to the surface, the limestone series being torn to pieces by it, and the bathyliths thus emerging being traceable over great areas, the foliation of the gneiss presenting great sweeping curves to which the courses of the lakes and rivers in this northern country conform. It will, therefore, be seen that in all its features this development of these pre-Cambrian rocks in the province of Quebec

conforms to those which have already been described from the areas visited by the committee.

In the eastern part of the original Laurentian area Logan found a large mass of anorthosite, which may be termed the "Morin anorthosite." This formed the eastern limit of the area which he mapped. This anorthosite he found to be in some places more or less distinctly foliated, which foliation he regarded as a survival of an almost obliterated bedding. He furthermore found that the limestone bands in the sedimentary series disappeared on coming against this mass of anorthosite. From these two facts he concluded that the anorthosite belonged to an unconformable, although highly metamorphosed, sedimentary series, which unconformably overlay the Grenville series, whose limestones he considered to pass beneath the anorthosite mass.

Adams, in continuing Logan's work to the east, had occasion to map and thoroughly study this anorthosite body. He found it to have the shape of a clover leaf and to have an area of 990 square miles. The anorthosite in the central portion, and over the greater part of the western half of the mass, is nearly massive, although often showing an indistinct brecciated structure. On going from the center of the mass toward its eastern boundary, however, this brecciated structure becomes more and more pronounced, the angular fragments being imbedded in a progressively larger amount of granulated ground-mass, while along the eastern border the mass becomes perfectly foliated, the angular fragments disappearing almost entirely. These angular fragments and the ground-mass are identical in composition, both being composed essentially of plagioclase. The fragments represent portions of the original coarsely crystalline rock in an uncrushed condition, the ground-mass being produced by the granulation and breaking-down of the original rock, of which the brecciated fragments are the surviving remnants. The fragments in the breccia, like the rock when in a massive form, are deep-blue in color, while the granulated rock has lost this blue color and is gray, sometimes nearly white. This is due to the disappearance of the minute inclusions so abundant in the plagioclase feldspar of all these anorthosites which have not been crushed. Where the rock becomes perfectly foliated, as along the eastern border of the anortho-

site mass, and especially in the narrow extension running off from the southern part of the area and representing the stalk of the clover leaf, the rock becomes perfectly white in color, so closely resembling a saccharoidal marble that the two can be distinguished only on making a trial of their hardness.

A detailed stratigraphical study of this mass proved undoubtedly that it was an igneous intrusion which had broken through the Grenville series, cutting off the limestone bands of the latter instead of covering them up, and which had been subsequently granulated by great pressure brought to bear upon the whole region from the east, seeing that it is on that side that the mass is most intensely granulated, while on the west granulation is confined to the immediate border of the mass.

With regard to the petrographic character of this anorthosite, it may be stated that it is composed almost exclusively of labradorite; augite, hypersthene, and a little iron ore being the other constituents. It is identical in character with most of the other anorthosite masses in the Laurentian of Canada. Hunt, in his early investigations of these rocks, stated that three-quarters of the anorthosite ooccurrences in Canada did not hold over 5 per cent. of minerals other than plagioclase.

It is to be noted that the foliation of the anorthosite, which is a secondary structure due to pressure, was already completed in pre-Potsdam times, for the perfectly foliated rock is overlain by horizontal beds of the sandstone in question.

In addition to this great intrusion of anorthosite, there are twelve smaller intrusions similar in character occuring in the area mapped by Adams.

In addition to these anorthosite intrusions, the sedimentary series, in the original area and in its extension to the east, is penetrated by several intrusions of more acid rocks. One of these consists of a mass of syenite which occurs in the township of Grenville and has an area of about thirty square miles, which is in its turn penetrated by a small body of feldspar porphyry, sometimes holding a small amount of quartz.

Another acid intrusion is represented by the great body of granite, in places developed in the form of coarse augen gneiss, which occurs

about twenty-five miles to the east of the Morin anorthosite intrusion. This possesses the ordinary character of such granitic rocks.

More especially in the southern portion of the "original Laurentian area" there also occur a great number of basic dikes, consisting for the most part of diabase, which represent, as a general rule, the latest intrusions of the district, and which persist across the front of the whole area from west of Grenville to a point north of the island of Montreal, where they disappear beneath the Ordovician cover. These diabase dikes were, however, considered by Logan to be older than the intrusion of syenite in the Grenville district already mentioned, which, in its turn, was older than the porphyry intrusion which cut it. While, therefore, in this original Laurentian area and its eastward extension there is not so great a relative proportion of rocks which are clearly of intrusive origin as in the case of the Adirondack area, intrusive rocks in very considerable variety and of the same general types are represented.

It is worthy of mention that in the Laurentian protaxis still farther to the east, in the district to the north of the Gulf of St. Lawrence and in the Labrador peninsula, a number of anorthosite intrusions of gigantic extent occur. Among these may be mentioned more especially one which may be referred to as the "Saguenay anorthosite," on account of the fact that it is developed about the head waters of this river. This, which resembles the Morin anorthosite in character, has an area of not less than 5,800 square miles. Another enormous area is traversed by the Moisie River, the Clearwater, a tributary of the Moisie, running through a great canyon in this anorthosite. Still others of similar extent might be mentioned. The occurrences of anorthosite which are now known to exist in the Labrador peninsula represent a total area of nearly 50,000 square miles.

As a result of his studies in the Grenville region, Logan announced his belief that the Laurentian system consisted of two great unconformable series of sedimentary rocks, to which he gave the names "Upper Laurentian" and "Lower Laurentian." The latter he considered to be again divisible into a lower and upper portion, which subdivisions he considered to be probably conformable to one another. In the course of time these several series came to be known

respectively as the "Anorthosite" or "Norian" series, the "Grenville" series, and the "Fundamental" or "Ottawa Gneiss." Logan's classification may thus be represented as follows:

Upper Laurentian		Anorthosite or Norian Series
Lower Laurentian	Upper Portion	Grenville Series
	Lower Portion	Fundamental or Ottawa Gneiss

The subsequent investigations by Adams in the district to the east of that studied by Logan showed that the Anorthosite (or Logan's Upper Laurentian series) really consisted of great intrusions, and that the associated limestones, etc., assigned by Logan to the "Upper Laurentian" were really part of the Grenville series. There therefore exist in these pre-Cambrian areas of the province of Quebec two divisions, namely, the Grenville series and the underlying Fundamental Gneiss. The relations of these have not been worked out in such detail as in the case of the Ontario area, but it is believed that here also the Fundamental Gneiss comes against the Grenville series with an intrusive contact.

VI. RECOMMENDATIONS OF THE COMMITTEE CONCERNING CORRELATION AND NOMENCLATURE

The committee considers that over the whole area covered by their investigations—namely, the Adirondack Mountains, that portion of eastern Ontario which they examined, the "original Laurentian area" in the province of Quebec and its continuation to the east as far as the river St. Maurice—the pre-Cambrian sedimentary development is represented by one great series. This series is essentially identical in petrographical character throughout the whole region.

The only locality where the possible (Coleman would say probable) existence of a second uncomformable sedimentary series was suggested by the facts observed, was that on the Queensboro road, east of Madoc, Ontario. It is, however, still a matter of uncertainty as to whether the conglomerate here developed marks the base of an overlying, infolded, uncomformable series or not.

In Logan's original classification of the Laurentian this term—apart from the Upper Laurentian which was proved to be composed essentially of anorthosite intrusions—included two series differing in character, namely, the Lower Orthoclase (Fundamental) Gneiss

and the Grenville series. Now that investigations have shown that these two series differ in origin, one being essentially a great development of very ancient sediments, and the other consisting of great bodies of igneous rock intruded through them, it becomes necessary to separate these two developments in drawing up a scheme of classification.

As the great intrusions of gneissic granite, forming what has been termed the "fundamental gneiss," have an enormously greater areal development than the overlying sedimentary series, constituting, as they do, a very large part of the whole northern protaxis, the committee recommend that the term "Laurentian" be restricted to this great development of igneous gneisses. The nomenclature suggested for the pre-Cambrian rocks of this eastern region will thus conform, so far as the use of this term is involved, with that suggested by the Special Committee for the Lake Superior region.[1]

For the overlying sedimentary series the committee recommend the adoption of the name "Grenville series," as it is the name originally given by Logan to the series as typically developed about the township of Grenville in the "Original Laurentian area" on the north shore of the Ottawa River, in the Province of Quebec, between the cities of Montreal and Ottawa. The term "Hastings series" in the opinion of the committee should be abandoned as a serial name, seeing that the development to which this name was applied by Logan is merely the Grenville series in a less altered form, as Logan in giving the name had conjectured was probably the case. The committee, however, think that it may in some cases be advantageously employed as a qualifying term to designate the less highly altered phase of the Grenville series, which may thus be referred to as the "Hastings phase" of the Grenville series.

In Canada this Grenville series everywhere on going north is invaded by and frays away into the great Laurentian bathyliths, while in the Adirondacks it is cut to pieces by the great intrusions of that area which, when worked out in detail, may prove also to have a more or less similar bathylithic form.

The following succession in this region is therefore recognized and adopted by the committee:

[1] See *Journal of Geology*, February–March, 1905.

Cambrian—Potsdam sandstones, etc.
(Unconformity)
Pre-Cambrian
Grenville series
(Intrusive contact)
Laurentian

The committee consider that it is inadvisable in the present state of our knowledge to attempt any correlation of the Grenville series with the Huronian or Keewatin, so extensively developed in the region of the Great Lakes. The Grenville series has not as yet been found in contact with either of these, and until this has been done and the relations of the several series have been carefully studied, their relative stratigraphical position must remain a mere matter of conjecture.

F. D. Adams
A. E. Barlow
A. P. Coleman
H. P. Cushing
J. F. Kemp
C. R. Van Hise

THE SEDIMENTARY BELT OF THE COAST OF BRAZIL

ORVILLE A. DERBY
Rio de Janeiro, Brazil

From a geological point of view the coast of Brazil can be divided into two principal sections according to the character of the highlands that either abut directly on the beach or at a moderate distance from it rise above the low costal plains, composed of sand flats and tidal- and fresh-water marshes, which are evidently of comparatively recent origin. In the southern section, extending from Cape Frio to the southern limit of the republic (this section might without impropriety be extended to the northern limit of the La Plata estuary) and embracing about one-third of the entire coast line, these highlands are composed of ancient metamorphic and eruptive rocks which are presumably of Archean or early Paleozoic age.[1]

[1] The only known exception is a comparatively short stretch of coast near the Porto de Torres, close to the northern boundary of the state of Rio Grande do Sul, where sandstones and eruptives of late Paleozoic or early Mesozoic age (Permian or Triassic, presumably the latter) abut on the coast.

In the northern section from Cape Frio to the southern mouth of the Amazonas (perhaps also the northern limit of Brazil) the highlands on or immediately back of the coast are, for the most part, composed of horizontal, or approximately horizontal, sedimentary beds of sandstone, shales, and clays, and more rarely of limestone. This costal belt of sedimentary rocks is usually quite narrow, and nowhere does it extend more than a few scores of kilometers from the coast. In the comparatively few and short stretches of coast where it is lacking—as at Cape Santo Agostinho and near Tamandaré in the state of Pernambuco, Bahia and Ilheos in the state of Bahia, and several points on the coast of Espirito Santo and Rio de Janeiro between the mouth of the Rio Doce and Cape Frio—it appears probable that it has been denuded away rather than that it was originally lacking. Its elevation is usually under one hundred meters, but in one district at least (near Alagoinhas in the state of Bahia) it is known to rise to an elevation of about 400 meters.

Although frequent references to local occurrences of this sedimentary belt are to be found in earlier writers,[1] the first geological contribution of value relating to it was made in 1850 by Allport (5), who described the occurrence of fossiliferous beds at Bahia containing carbonized wood, cyprids, fish and reptile remains, and fresh-water mollusks that were referred to the Cretaceous age. The first general account of the belt was, however, given in 1870, by Hartt (4) who had personally traced it from Cape Frio to Pernambuco. After discriminating the recent consolidated beaches or stone reefs, which are so frequent on this coast and so liable to mislead the geologist, Hartt

[1] In 1811 Feldner, a German engineer in the employ of the Brazilian government, made explorations for coal in this belt, which were based on the occurrence of fragments of carbonized wood in the neighborhood of Bahia. Spix and Martius (1) briefly described some of its outcrops of Bahia and near Ilheos, considering those at the former place as of recent formation and those at the latter as equivalent to the European *Quadersandstein*. The identification in the latter case was evidently based solely on lithological resemblances, and in the former on fossils supposed to come from its rocks which were evidently confounded with those of the consolidated beach, or stone reef, later described by Hartt (4) and Branner (11)—a not unnatural error. Pissis (3) in 1842 mapped quite acccurately the Bahia basin as extending down the coast to beyond Marahú, but, misled by shells from the above-mentioned consolidated beach, or more probably and less excusably by the shell-heaps on the island of Itaparica described by Rathbun (9) which he erroneously attributed to the section at Monserrate Point, he determined the formation as Tertiary.

referred the beds of the sedimentary belt proper to the Cretaceous and the Tertiary; the former represented by several detached and somewhat disturbed basins of the fossiliferous sandstones, shales, and limestones; the latter, by more widespread and continuous undisturbed (except perhaps by vertical movements) beds of soft sands and clays which clearly overlie the fossiliferous ones. The recognized fossiliferous (Cretaceous) basins were on the Abrolhos islands(with indeterminable plant and fish remains, and associated with eruptive rocks that are not known elsewhere in the belt), at Bahia and vicinity, near Maroim, Propriá, and Santa Luzia in the state of Sergipe, and, based on information that was afterward proved to be reliable, near Pernambuco and Parahyba. Of these basins, those of the Abrolhos and Bahia are of fresh (or brackish) water origin, the others being marine. From the Mariom district a number of typical Cretaceous fossils were obtained and described, but for the other localities no critical study of the fossils was made. Aside from lithological differences, Hartt's principal criterion for discriminating the Cretaceous from the Tertiary, which had not afforded fossils, was the somewhat disturbed position of the former while the beds referred to the latter are undisturbed.

In his expedition to the Amazonas in 1870, immediately after the publication of his book, Hartt dispatched two of his assistants, of whom the present writer was one, to Pernambuco to examine the fossiliferous locality reported near that place. The result was a small collection from the limestone rock of the small river Maria Farinha, a few miles north of the city, which were described by Mr. Rathbun (**6**), who referred them to the Cretaceous, without, however, finding any forms decidedly characteristic of that age. In 1875 Hartt personally visited the locality, accompanied, among others, by Dr. J. C. Branner, and secured a large and varied collection for the Geological Commission of Brazil, of which he was chief. In the following year Branner made a careful examination of the Sergipe basin,where a large collection was also made. In the same year the present writer obtained through a friend, a few blocks of highly fossiliferous limestone from the river Pirabas (by error this name was given as Piabas in the notes furnished to Dr. White (**10**) for his monograph on the Brazilian fossils), just south of the southern mouth of the Amazonas, containing a number of species

identical with those of the Pernambuco basin. Some years later he was shown fragments of fossiliferous limestone from near Mossoró, in the state of Rio Grande do Norte, that indicated the existence of another similar marine basin in that region; and recently Branner (**12**) has shown that a fresh-water formation similar to that of Bahia occurs along a considerable part of the coast of the state of Alagoas to the northward of the city of Maceio.[1]

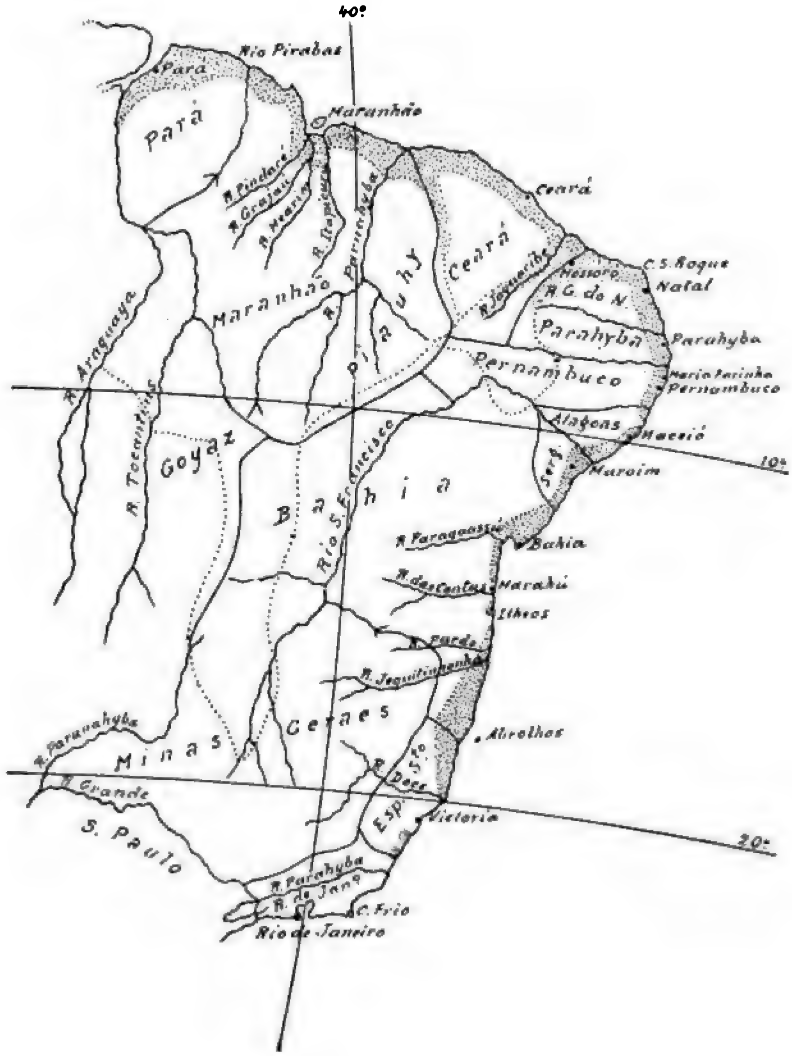
Gonzaga de Campos (**15**) has recently shown that the fresh-water formation of Bahia extends southward along the coast to Marahú, where it is associated with marine beds containing a fauna similar to that of Sergipe, while unpublished observations by Ennes de Souza and the present writer show that another basin of the same character exists farther southward in the neighborhood of Ilheos.

The approximate interior limit of this sedimentary belt in the section from the state of Espirito Santo to Rio Grande do Norte has been given in several recent papers by Branner (**12**, **13**, **14**), but without attempting to discriminate the two members above indicated, which with our present knowledge is indeed an impossible task. The accompanying sketch map is in great part compiled from the various maps accompaning his papers. Throughout the section of the coast here represented to Cape St. Roque the higher lands lying back of the sedimentary belt are composed of very ancient metamorphic rocks, for the most part probably Archean, with their accompanying eruptives, though in a few places (Lower Jequetinhonha and Rio Pardo, Inhambupe near Bahia, and Serra de Itabaiana in Sergipe), unmetamorphosed beds, probably of early or middle Paleozoic age, are known to occur. Farther northward, in the states of Ceará, Piauhy, Maranhão, and Pará, it is probable that they abut against or perhaps merge into, the high-lying beds of presumably Mesozoic age that form the table-topped hills and ridges so characteristic of considerable portions of those states. It is possible also that in the three latter states they will be found in close connection with late Paleozoic (Permo-Carboniferous) strata. Regarding these points, however, nothing is definitely known.

As above stated, the strata of this sedimentary belt fall on the

[1] The origin of the bituminous shale described by M. Bertrand (*Travaux et Mémoires de l'Université de Lille*, VI. Mem. 21, 1898) from Ceará is not certainly known.

most casual inspection (which, except in limited areas, is all that it has yet received) into two distinct divisions, each of which will



doubtless be found susceptible of subdivision. These are: (1) a lower series of sandstones, shales, and limestones, which are in part fossiliferous, and which have been subjected to slight earth-movements, giving the beds a moderate but irregular dip; and (2) an

upper series of soft sandy and clayey sediments that for the most part is without fossils and undisturbed by earth-movements of a character to affect the horizontality of the beds. So far as known to the writer, in no place have these two series been seen in actual juxtaposition, and an unconformability between them is rather assumed than actually proven. In each series there are beds, especially the sandy ones, that closely resemble each other, so that their discrimination is often a matter of doubt.

Following Allport, and Hartt, and the various paleontologists to whom their material was submitted, the lower series has been referred to the Cretaceous and the upper to the Tertiary. This classification has lately been questioned by Branner (**12**, **13**, **14**), who is inclined to refer to the Tertiary much that has hitherto been called Cretaceous. In his recent examination (the most complete and minute that has yet been made) of the coast from Natal, Rio Grande do Norte, to Caravellas in southern Bahia, he found that none of the physical characteristics (lithological character, coloring, inclination of the beds, etc.) can be depended upon for the discrimination of the two series, though he does not put in doubt their actual existence. In examining the paleontological evidence, he finds that unequivocal Cretaceous marine types have been found only in the Sergipe basin and at Parahyba, and that the general aspect of the faunas of the Pernambuco (Maria Farinha, Olinda, and Ponto das Pedras) and Pará basins is decidedly Tertiary rather than Cretaceous, and that the same is the case with the invertebrates of the Bahia fresh-water basin.[1]

These doubts of Dr. Branner are undoubtedly well founded, and in a recent excursion in the region about Bahia and Ilheos I fully sympathized with him in his difficulties in determining the dividing line between the upper and the lower series, and like him I referred to the latter a number of outcrops that formerly I should

[1] In the earlier of his papers embodying this view Branner refers these supposed Tertiary faunas to the Eocene, and quotes Dr. Gilbert D. Harris to the effect that the marine forms are probably not older than the Midway Eocene. In his latest paper (**14**), however, he mentions Cretaceous cephalopods from one of the Pernambuco localities, and quotes a letter from Dr. Smith Woodward to the effect that the vertebrates of the Bahia Basin suggest a doubt as between Jurassic and Cretaceous rather than between Cretaceous and Tertiary.

unhesitatingly have referred to the former. Such perplexities are not unknown in other regions where the difficulties of geological study are far less than in Brazil, and where the number of geological students to set about unraveling them is far greater. They are of great importance when attempts at areal geology are to be made, but for the region in question they may for the present be put aside. The really important questions for the moment are: Is the reputed division into an upper and a lower series a real one; and, if so, what part, if any, of the latter belongs to the Cretaceous?

Dr. Branner apparently does not put in doubt an affirmative answer to the first of these questions, and this, therefore, can be summarily put aside. In regard to the second he expresses serious doubts, which, however, seem to have varied from time to time; and this makes it desirable to discuss the question, locality by locality.

The fossiliferous beds of all the numerous Sergipe localities examined by him are unhesitatingly set down by Branner as Cretaceous, and the overlying non-fossiliferous ones are referred to the Tertiary, apparently on the same stratigraphical and topographical criteria that were used by Hartt and others. Some of the species are admitted by him to present a decidedly Jurassic aspect, and on referring to Dr. White's memoir we find that their number (nine) is somewhat in excess of that (seven) cited from the Pernambuco beds to establish their Tertiary age. Curiously enough, the beds containing the greater number of these species of Jurassic aspect are the same that carry the greater number of the species common to the Pernambuco and Pará beds which Branner would refer to the Tertiary, and the most decided Jurassic form of all (an Ammonite) is from a bed that is referred to the top rather than to the bottom of the series which is given as presenting a considerable vertical range. The most characteristic Cretaceous forms are the Ammonites, represented by fourteen species, of which only three occur in the three localities most abundant in other mollusks. If, therefore, by the chances of collection, only these localities had been examined, and if these few Ammonites had been overlooked, a doubt regarding the Sergipe basin as between Jurassic and Cretaceous might have been raised on the same ground as that raised between Cretaceous and Tertiary for the Pernambuco and Pará basins. Some of the other localities,

however, present a well-characterized Cretaceous fauna, which, as a whole, can be taken as typical of the marine Cretaceous of the Brazilian coast region, although it is to be noted that only five species are positively identified as occurring elsewhere.

In the Pernambuco district the principal locality is Maria Farinha, which has furnished seventy-three species of invertebrate fossils which, in the opinion of a number of prominent European and American paleontologists, present a more decidedly Tertiary than Cretaceous aspect. Of these species two are Echinoids, of which one is referred to a characteristic Cretaceous genus (Toxaster) and the other to a new genus, which is therefore unavailable for correlation. Of the seventy-one mollusks, the single Cephalopod and four of the sixty-eight Gasteropods are referred to species known outside of Brazil. These are: *Nautilus sowerbyanus* d'Orb., *Volutilithes radula* Sow., *Nerinea inaugurata* Stoliczka, *Euspira pagoda* Forbes, and *Turretella elicita* Stoliczka. Branner, on the basis of a study by Dr. Ralph Arnold, questions the identification of the second and fifth of this list, and cites the first two as characteristic Tertiary (*sic*) forms. Even if these doubts be admitted, there would still remain two Cretaceous against two Tertiary forms, whereas White gives four Cretaceous against no Tertiary forms. In any case, the evidence from known species is weak and may very properly be considered as inconclusive for either reference, though note should be taken of the presence of the characteristic Cretaceous genera Toxaster and Nerinea.

The evidence for Cretaceous age to be drawn from a comparison with the Sergipe fauna is somewhat stronger, though still less conclusive than could be desired. Six species, including one of those above mentioned (*Euspira pagoda*), are identified as common to the two regions. When it is considered that the Pernambuco and Pará faunas, whose correlation no one seems inclined to contest, have only twelve (or fifteen including three doubtful forms) species in common, this showing is not so unfavorable as might at first sight appear, and affords at least a stronger presumption in favor of the Cretaceous than any I have yet seen cited in favor of the Tertiary age.[1] This presumption is greatly strengthened by Branner's state-

[1] The list of Tertiary forms presented by Branner in his latest discussion of the subject (*The Stone Reefs of Brazil*, p. 15) includes, besides the two cited above given by

ment that he saw in the possession of a gentleman at Pernambuco specimens of Cephalopods that he calls Cretaceous, from the limestone of the island of Itamarica, close by Maria Farinha, and that he himself collected on the same island one of the most characteristic of the Maria Farinha fossil shells.[1] As no good reason has yet been presented (from my personal knowledge of the district I doubt that any can be presented, for presuming that there are two widely distinct fossiliferous formations in this vicinity, it is reasonable to assume that the lack of strongly characteristic Cretaceous types in the collection submitted to Dr. White for study was due to the chances of collecting, and that, if the island of Itamarica had been thoroughly explored, the general aspect of the Pernambuco fauna would have come out with much greater similarity to that of Sergipe. The other Pernambuco localities, Olinda and Ponta de Pedras, have been shown by Branner to be clearly correlated with that of Maria Farinha, and therefore need not be discussed here.

The Parahyba locality, being set down by Branner as unquestionably Cretaceous, need only be noted as another example of the collector's chance—in this case a particularly happy one, as only three recognizable fossils were obtained. It seems reasonably probable that this and the Pernambuco localities will eventually prove to be remnants of a single original basin.

The Mossoró or Apody basin, in the state of Rio Grande do Norte, is very imperfectly known. My recollection of the impression given several years ago by the casual inspection of fragments of limestone with imperfectly preserved fossils is that the fauna

White as characteristic Cretaceous forms, five others that have not as yet been found in other localities, either in Brazil or elsewhere, and belonging to genera which might be either Cretaceous or Tertiary.

[1] Another fossil from the same locality is referred to a species occurring in the fresh-water beds of Bahia—a rather singular combination, which is repeated at Ponta de Pedras, where this and still another characteristic fresh-water form are reported in association with a well-characterized marine fauna.

With reference to the discovery of Cephalopods (Ammonites ?) in the limestone of Itamarica, it may be remarked that this and Branner's discovery of fossils at Parahyba seem to confirm an instinctive feeling that I have long had, that wherever fossiliferous limestones are found in this sedimentary belt their fauna will be found to present a more characteristic Cretaceous aspect than that of the arenaceous and argillaceous beds. From several chance remarks it seems that Branner had the same impression.

would eventually prove to be similar to that of the Pernambuco beds.

The Pará basin (9, 10) has furnished fifty-two species of mollusks (Lamellibranchs and Gasteropods), and as these were obtained from a few loose blocks picked up at a single point at the mouth of the Rio Pirabas, it is to be presumed that the fauna is a much richer one. Indeed, Kraatz-Koschlau (16) states that corals, echinoids, and reptiles also occur, but as yet nothing is known of their character. With one doubtful exception (*Pteria linguiformis* Evans & Shumard), all of these species are as yet unknown outside of this Brazilian coast belt, although six are cited by Ortman (Branner, 14) as closely resembling Tertiary species from Patagonia. Twelve (or fifteen including three doubtful forms) are identified as occurring also at Maria Farinha, and seven (including two found also in the Pernambuco basin) in Sergipe. The general aspect of the fauna is stated by good authorities to be decidedly Tertiary, but, so far as I can learn, no distinctively Tertiary genera or species have been cited from it, whereas the occurrence of several species that are found also in Sergipe affords a reasonable presumption that, with more extensive collections, characteristic Cretaceous forms are liable to turn up. As already remarked, a chance collection made from certain of the Sergipe localities might readily have been equally equivocal in general aspect, owing to the deficiency of representatives of characteristic Cretaceous genera.

The evidence of a correlation between the Pará and the Pernambuco faunas is somewhat stronger, in a positive sense, than that of the Pará and Sergipe ones, due to the presence of a greater number of species in common; and is decidedly stronger in the absence of characteristic Cretaceous forms. This last argument for a Tertiary age will, however, break down if Branner's casual identification as Cretaceous of the Cephalopods seen at Pernambuco be accepted as final.

One of the most interesting localities of the whole sedimentary belt is that of Marahú, about 60 miles south of the city of Bahia, since here the marine and fresh-water fossiliferous members of the series are found in close juxtaposition. This locality will be discussed below, and only the marine fossils will be mentioned here.

A small collection brought from there by Gonzaga de Campos (15) represents an earthy limestone bed and one of calcareous mudstone, both being quite similar in appearance to some of the beds of the Sergipe basin. The limestone has afforded a pectinoid shell apparently identical with *Neithea quadricostata* Sow., which is a very characteristic form of the Sergipe limestone, and a small echinoid. The fossils from the mudstone represent species of *Cucullaea*, *Cardium*, *Corbula*, *Crassatella*, *Isocardia*, and *Tellina*, closely resembling, if not identical with, the representatives of these genera in the beds of similar material of the Sergipe basin. Although no critical comparison of the species could be made, there can be little doubt that the marine beds at Marahú represent substantially the same geological horizon as those about Maroim, in the state of Sergipe.

With regard to the fresh, or rather brackish, water deposits of the neighborhood of Bahia and other parts of the coast belt, Branner's doubts of the correctness of their reference to the Cretaceous seem to have been based, in the first instance, on the modern aspect of the mollusks that occur in them, being afterward somewhat modified, though not entirely withdrawn, by Woodward's statement, above referred to, that the vertebrate fossils are of Mesozoic types. In his latest reference to the subject (14) he suggests that possibly the vertebrate and molluscal elements of the fauna may belong to two distinct formations which have not been defined and separated from lack of proper stratigraphical and paleontological work, and notes appearances that suggest an unconformability between beds of two separate ages. Dr. I. C. White, who has also visited the typical locality at Monserrate Point, informs me that he also noted an appearance of unconformability that may possibly explain the apparent disaccord of the two fauna-elements.

In a recent visit to Bahia the typical section was examined with these doubts in mind. The stratification is very confused, layers of conglomerate, sandstone, and shale being mingled in a most perplexing manner and disturbed by a number of minor folds. The molluscan remains occur in thin layers and detached lenses of limestone, and in no case were they found in immediate association with the vertebrate remains. They were, however, found both above and below one of the lines that best simulates an unconformable contact,

and in one lens they were associated with plant remains, in the characteristic form of jet, which is of frequent occurrence in the layers containing fossil vertebrates. In short, the re-examination of the section with this point especially in view convinced me that it represents a geological unit. At the other locality, near Pojuca station, where mollusks occur, Mr. Mawson, a very competent and painstaking observer, reports (10) vertebrate and molluscan fossil from the same layer of only a few inches' thickness.

In view of these observations, the hypothesis of an admixture, through careless collecting, of fossils from two distinct formations may be safely put aside, and as the molluscan fauna is a comparatively characterless one, but little weight should be given to it as against the well-characterized Mesozoic forms of the vertebrate fauna.

The strictly fresh-water faunal elements of the Bahia basin are not sufficiently widespread, either in horizontal or vertical range, to characterize the formation as a whole, and it seems probable that, instead of being in a strict sense a fresh-water basin, it was rather an estuary or semi-detached arm of the sea in which deposits characteristic of fresh, brackish, and salt water might be laid down in different parts (or at different epochs in the same parts) and in close connection, or rapid alternation, with each other. A widespread and characteristic feature is the terrestrial elements represented by plant and dinosaurian remains. The former are represented by scattered fragments of carbonized wood, usually in the form of more or less pulverulent lignite in the sandstones and of jet in the shales.

Throughout the district the beds with recognizable fossils are overlain by soft sandstones, which, when they show plant remains or are distinctly inclined, have been referred to the Cretaceous, and in the contrary case to the Tertiary. As Branner has pointed out these criteria are unsafe ones, and doubtless some errors have been committed. My own impression is that in most cases these errors will prove to have been in the sense of placing the limit between Cretaceous and Tertiary too low down, rather than, as Branner seems to think, not low enough. The plant-bearing beds are often horizontal, or apparently so, over considerable areas, and if, as may readily happen, no plant remains are observed in such areas, they may erroneously be referred to the Tertiary. Indeed, it is by no means

certain that a horizontal position, even when general, is a sure index of Tertiary age, although this hypothesis has, for this region, a strong presumption in its favor. Thus far the only known fossils in the beds referred to this age are the leaves of Ouriçanguinhas from the high tableland (400 meters) back of Alagoinhas, which has been referred to the Pliocene (**17**, **18**). As all the species are described as new, it is possible that they may prove to be somewhat older. Between this horizon and that of the fossiliferous beds discussed above there is almost certainly one (and there may be several) geological divisions to be established; but where the dividing line, or lines, between them—that is to say, between some horizon, probably not the extreme upper one, of the Cretaceous and a horizon of the upper Tertiary—is to be drawn must remain a subject for future study. Branner's protest against drawing it at the top of the known fossiliferous beds is a timely one, and his reserve in the matter of indicating another position for it is significative of the difficulties of the subject.

From Bahia southward for a considerable distance along the coast sedimentary beds similar to those about the bay have been reported from a number of points, so that it is tolerably certain that the formation is, or was formerly, continuous from Bahia to the region of Marahú which has recently been examined by Gonzaga de Campos (**15**), and more cursorily by myself. The former reports, in addition to the marine beds already mentioned, a sandstone with carbonized wood which he compares very properly with the similar strata about Bahia. The relative position of the marine and fresh-water beds could not be positively determined, but he was inclined to think that the former overlie the latter. Without being positive on the subject, it seems to me that the contrary will prove to be the case. These beds scarcely rise above tide-level and can be well seen only at extreme low tide, so that a proper examination of their numerous widely separated localities involves many days' labor. The soft particolored sandstone most in evidence in the region is apparently without fossils and apparently horizontal, and for these reasons Campos referred it to the Tertiary, and assumed that the "turfa"[1] deposits

[1] The so-called turfa of Marahú is, in part, a peculiar light (sp. gr. 0.92), nonschistose, bituminous substance of earthy aspect and yellow color, containing about 70

that have made the place famous, and that were mainly under water at the time of his visit, also belong to that age. The occurrence of fossil leaves of modern aspect in the turfa seemed to him to confirm this view.

At the time of my visit a boring had been made into the turfa beds and, the pit excavated in them being freed from water, a number of interesting features that escaped Campos' observation could be seen. A gentle flexture has brought above tide-level, at the oil-works, a series of shale beds which are covered by heavy beds of soft sandstone that participated in the flexture. The shales were penetrated by the boring to the depth of about 30 meters, but, as the record was not at hand no accurate account of it can be given. At the top, above the beginning of the boring and immediately underlying the sandstone, is a bed, 4 meters thick, of marahuite containing fossil leaves. The boring penetrated clay shale with intercallations of rich oil-shale for a depth of about 20 meters, then a thin layer of sandstone, and stopped at the top of a second shale bed. As shown by fragments of the core that had been preserved, a lower layer of marahuite was met with somewhere in the midst of the shale series, which also carries fossil leaves, of which a small collection has been forwarded to Dr. David White. Cutting the shale beds and penetrating into the marahuite (where they become diffused as an asphaltic impregnation) are thin (1-2 centimeters) stringers of a coal-like substance which, so far as can be made out, is quite similar to the albertite of Nova Scotia. The marine beds of the district are reported by Campos at a distance of about 2 kilometers to the southward and eastward of this locality, and it seems to me tolerably certain that they underlie the shale beds. This

per cent. of hydrocarbons, 10 per cent. of fixed carbon, and 15–20 per cent. of ash which is peculiar in consisting in great part of alumina soluble in acids. Campos, who has made a careful study of it, showed that it has essentially the composition of the so-called Boghead coals which, as Bertrand has shown, consist of a fundamental yellow base with a secondary infiltration of asphalt. As employed at Marahú, the term also covers a dark-colored shaly material, which is a true oil shale in which the hydrocarbons are of a somewhat different composition and the earthy element of the ash is argillaceous. Both give a high yield of gas and oil, and in the attempts to work the material were used indiscriminately under the general name of turfa. Although the yellow material is perhaps a true boghead, it is sufficiently different from the ordinary type to merit a distinctive name, and it may be called Marahuite.

seems to be confirmed by an observation made by Campos about 8 kilometers to the northward, where he found a shale with carbonized wood overlying the marine limestone and underlying the Tertiary(?) sandstone. All things considered, I have little hesitation in identifying the shale series at Marahú (with the included marahuite) with the Cretaceous series at Bahia, and in including in it a large part, if not all, of the so-called Tertiary sandstone at the former place. It is to be hoped that other borings will soon be made in this interesting locality that will settle these doubtful points.

The metamorphic highlands lying back of the sedimentary belt at Marahú extends down to the coast a few kilometers to the south of the town and abut on the coast for a distance of about a score of kilometers. To the southward the sedimentary belt again appears in the neighborhood of the town of Ilheos. The shales and sandstones composing it closely resemble, both to the north and the south of the town which is on a point of crystalline rocks, those about the bay of Bahia, and this correlation is fully confirmed by a fine collection of fossils made some years ago by my friend Dr. Ennes de Souza, which I lately had an opportunity of examining. The characteristic features of this collection are the fossil ganoid fishes and fragments of jet, both of which are very characteristic of the formation at Bahia. Fortunately, arrangements have about been completed for having this collection studied by a competent paleontologist.

From Ilheos southward to near Victoria, in the state of Espirito Santo, the sedimentary belt is unbroken, except by valleys of denudation, but no outcrops that can be definitely referred to the Cretaceous are known, though it will not be surprising if much of the so-called Tertiary sandstone of this section of the coast should eventually prove to be of that age. In front of the southern portion of this section, at a distance of about 40 miles from the mainland, lie the Abrolhos islands, where Hartt (4) reports fossiliferous limestone, shale and sandstone which he compared with the strata about Bahia. No recognizable fossils were found, but plant impressions and markings resembling scales of teleostean fishes were observed. The beds are somewhat inclined and are overlain by a sheet of basaltic trap. Specimens of this rock collected by Dr. Branner have been examined by Dr. J. P. Iddings, who determined it to be an olivine-gabbro-

diabase. Similar rocks characterize a large region in southern Brazil, where they are presumed to be of Triassic age. As no signs of eruptive activity have been detected in the sedimentary belt of the mainland, it is possible that the Abrolhos outcrop may prove to be somewhat older than those above discussed. However this may be, it must be regarded as a remnant of the same costal sedimentary belt representing a considerable, perhaps the major, portion of it that has disappeared on the submerged border of the continent.

Branner (12) has described several outcrops of oil-shale on the coast of the state of Alagoas, in some of which he found plant remains, and in one a fossil fish identified with a species occurring at Bahia. There can be little doubt that these various deposits are to be correlated with those containing fossil plants and fishes at Bahia, Marahú, and Ilheos. Vague information relating to the northeast section of the coast between Pernambuco and the mouth of the Amazonas indicates that at various points similar deposits occur along it.

The information at present available regarding the unmetamorphosed geological formations of the coast of Brazil may be summarized as follows:

1. With the exception of comparatively rare and short sections, the whole coast from Cape Frio northward is formed, in its highland portions, by Mesozoic and Tertiary sediments, with which are associated eruptives of basic character at the Abrolhos islands.

2. In the southern section of the coast, from Cape Frio to the eastern shoulder of the continent at Cape St. Roque, these sedimentary rocks form only a narrow belt and abut against, or overlap, the margin of a shield-shaped mass of Archean(?) metamorphic and crystalline rocks, fringed in places (rarely along the Atlantic border region) by sharply inclined early Paleozoic strata. In the northern section, from Cape St. Roque northward to the mouth of the Amazonas, they in places extend far inland, occupying baylike indentations in the margin of the Archean (?) shield, or abut against older (?) Mesozoic (Ceará in the semicircle of sedimentary table-lands—Serras de Apody, Araripe, and Ibiapaba—that surround a minor shield in the central part of that state), or late Paleozoic (Piauhy, Maranhão, Pará, and northern Goyaz) strata that form the high

sedimentary table-lands of the Jaguaribe, São Francisco, Parahyba, coast rivers of Maranhão and Pará, and Araguaya-Tocantins basins.[1]

3. The oldest fossils known from this series present a preponderance of Cretaceous types, but with certain forms that standing alone would be referred to the Jurassic; the newest are of late Tertiary (Pliocene ?) types. The geological range is therefore from early(?) Cretaceous to Pliocene, thus embracing both Mesozoic and Tertiary strata.

4. Certain localities representing strata at or near the base of the series present faunas with a decidedly Tertiary aspect,[2] but with a small number of species that occur also in the typical Cretaceous beds. The geological horizon of the beds at these localities is therefore somewhat doubful, but for the present the preponderance of evidence seems in favor of a Cretaceous age.

5. The typical fossiliferous Cretaceous beds are usually somewhat disturbed, whereas the typical Tertiary ones are undisturbed, except probably by vertical movements; and, in the absence of other evidence, this circumstance has been used as a criterion for discriminating the Mesozoic and Tertiary members of the series, but it is obviously an unsafe one. The assumption that the unconformability that doubtless exists is at the contact of the Cretaceous and Tertiary is a plausible one, but is unproven. The evidence of conformability or unconformability is frequently very obscure, and thus becomes practically valueless in rapid reconnaissance work.

Between the fossiliferous Cretaceous beds at the base of the series and the fossil leaf-bed near the top there is, in the Bahia section,

[1] These indentations are represented schematically by dotted lines on the map on p. 222. Cretaceous fossils are known from these table-lands from southern Ceará, eastern Piauhy, and on the São Francisco below the great bend; and Permo-Carboniferous ones from the interior of Piauhy, and on the Maranhão. The great bay embracing a part of the São Francisco valley follows quite closely a larger and older Eo-Paleozoic one that over a great part of that region occurred between the Archean (?) shield of Bahia and Eastern Minas Geraes, and a second (not entirely detached from the first) in Goyaz.

[2] Compared by Professor G. D. Harris, (14 p. 18) with the fauna of the Eocene beds at Midway, Ala. The resemblance is certainly a striking one, but, as above shown, its significance is greatly weakened by the recent discovery of a typical Cretaceous genus (Ammonites ?) in the immediate vicinity of one of the localities affording this doubtful fauna, and presumably from a bed belonging to the same geological horizon.

a thickness of at least 200 meters (and probably considerable more) of strata that, thus far, have not afforded fossils, except unrecognizable fragments of carbonized wood in their lower part, so that there is no paleontological evidence as to where the division line should be drawn. At about 50 meters below the leaf-bed there is a change in the character of the rock, marked by a water horizon, which apparently indicates a break in the succession; but what its significance may be has not been determined. The beds below this horizon are somewhat more argillaceous than those above, and are more widespread, so that there is here an indication of unconformability by overlap. They are also more widespread than the beds below them that can be definitely assigned to the Cretaceous, but they are so like the upper arenaceous members of the latter series as to be inseparable from them without more study than has yet been given to the subject. These intermediate beds of the Bahia section may be presumed to represent the greater part of the so-called Tertiary of the costal region, and while there is a reasonable presumption that they will prove to belong to the early or middle parts of that age, it cannot be definitely proven that they are not upper Cretaceous.

6. The outlines, so far as they have been determined, of the various fossiliferous deposits of the costal region, and the character of their rocks and fossils, indicate that they were formed in estuaries, or partially closed litoral basins, in which marine, brackish, and freshwater sediments might be laid down simultaneously in different parts; or alternately in the same parts. In view of this circumstance, much detailed study will be required to make out the details of the true succession of the different beds and their respective faunas. In the light of our present knowledge, the *apparent* succession is as follows, in ascending order:

a) A marine group, represented in Sergipe and at Marahú, well characterized by a Cretaceous molluscan fauna which in part shows Jurassic affinities.

b) An estuarine group, represented about Bahia (including Marahú), Ilheos, and the oil-shale localities of Alagoas, with a well-characterized Cretaceous vertebrate fauna, which also in part shows Jurassic affinities, land plants and reptiles, cyprids, and rarely freshwater mollusks.

c) A marine group, represented in Pernambuco, Pará, Parahyba (?), and Rio Grande do Norte (?), with a molluscan fauna showing strong Tertiary affinities, but containing several representatives of the fauna of group No. 1.

Unconformability (?).

d) Soft particolored sandstones and clays without known fossils, that practically cover the whole marine belt from Espirito Santo to Pará.

e) Soft red sandstones with intercallated clay layers containing fossil leaves of Pliocene (?) age, represented in Bahia and Sergipe (?) in a limited area to the northward of the bay of Bahia.

7. To the southward of Cape St. Roque the Cretaceous coast-line was not very different from the present one, but lay in places somewhat farther inland, and in others somewhat farther seaward on the submerged border of the continent.[1] Later (if the Tertiary (?) beds prove to be marine) the coast-line swung considerably farther inland. To the northward of Cape St. Roque the Cretaceous coast-line was much more different from the present one.

BIBLIOGRAPHY

1. SPIX and MARTIUS. *Reise in Brasilien.* (Munich, 1823–31.)
2. ESCHWEGE, W. L. *Beiträge zur Gebirgskunde Brasiliens*, pp. 387–95. (Berlin, 1832.)
3. PISSIS, A. Memoire sur la position géologique des terrains de la partie australe du Brésil etc." *Mémoires de l'Institut de France*, Vol. X, pp. 398, 399. (Paris, 1842.)
4. HARTT, C. F. *Geology and Physical Geography of Brazil.* (Boston, 1870.)
5. ALLPORT, S. "On the Discovery of Some Fossil Remains near Bahia in South America. *Quarterly Journal of the Geological Society*, Vol. XVI, pp. 263–66. (London, 1850.)
6. RATHBUN, RICHARD. "Preliminary Report on the Cretaceous Lamellibranches Collected in the Vicinity of Pernambuco, Brazil, etc." *Proceedings of the Boston Society of Natural History*, pp. 241–56. (Boston, 1875.)

[1] The absence of late Paleozoic and early Mesozoic strata in the coastal region of this section, together with the occurrence of Mesozoic (?) beds at the Abrolhos near the margin of the submerged continental border, suggests the hypothesis that from early Paleozoic to middle or late Mesozoic times the land area extended to near this margin, and that a transgression then occurred which established marine and estuarine conditions over a broad belt of which only remnants now remain.

7. RATHBUN, RICHARD. "Observações sobre á geologia: Aspecto da Ilha de Itaparica na Bahia de Todos os Santos." *Archivos do Museu Nacional*, Vol. III, pp. 159–83. (Rio de Janeiro, 1878.)
8. DERBY, O. A. "A bacia cretacea da Bahia de Todos os Santos." *Archivos do Museu Nacional*, Vol. III, pp. 135–58. (Rio de Janeiro, 1878.)
9. ——"A Contribution to the Geology of the Lower Amazonas." *Proceedings of the American Philosophical Society*, Vol. XVIII, pp. 155–78. (Philadelphia, 1880.) *Archivos do Museu Nacional*, Vol. II. (Rio de Janeiro, 1877.)
10. WHITE, C. A. "Contribuições á palaeontologia do Brazil." *Archivos do Museu Nacional*, Vol. VII. (Rio de Janeiro, 1887.)
11. BRANNER, J. C. "Cretaceous and Tertiary Geology of the Sergipe-Alagoas Basin of Brazil." *Transactions of the American Philosopical Society*, Vol. XVI, pp. 369–434. (Philadelphia, 1889.)
12. ——"The Oil-bearing Shales of the Coast of Brazil." *Transactions of the American Institute of Mining Engineers*, Vol. XXX, pp. 537–54. (New York, 1901.)
13. —— "Geology of the Northeast Coast of Brazil." *Bulletin of the Geological Society of America*, Vol. VIII, pp. 41–90. (Rochester, 1901.)
14. —— "The Stone Reefs of Brazil." *Bulletin of the Museum of Comparative Zoölogy*, Vol. XLIV, pp. 8–32. (Cambridge, 1904.)
15. CAMPOS, L. F. GONZAGA DE. *Reconhecimento geologico e estudo das substancias bitunino-sas de bacia de Rio Marahu, Estado da Bahia.* (São Paulo, 1902.)
16. KRAATZ-KOLSCHLAU, K. V. und HUBER, J. "Zwischen Ocean und Guama." *Memorias do Museu Paraense*, Vol. II. (Pará, 1900.)
17. KRASSER, F. "Konstantin von Ettinhaussens Studien über die fossile Flora von Ouriçanga, Brazilien." *Sitzungsberichte der kaiserlichen Akademie der Wissenschaften*, Vol. CXII, pp. 1–9. (Vienna, 1903.)
18. BENNET, E. DE. "Contribution à la flore pliocène de la province da Bahia (Brésil)." *Bulletin du Musée de l'histoire naturelle*, pp. 510–12. (Paris, 1905.)

REDISTRIBUTION OF ELEMENTS IN THE FORMATION OF SEDIMENTARY ROCKS[1]

WARREN J. MEAD

PROBLEM

Sedimentary rocks are derived from the destruction of older rocks—igneous, crystalline, and sedimentary. The pre-existing sedimentary rocks may themselves have come from still earlier sediments, and these in turn from earlier ones, and so on back, but ultimately their derivation may be traced to the igneous and crystalline rocks, the latter term being used to include schists and gneisses resulting from the metamorphism of the igneous and sedimentary rocks, and others whose origin cannot be determined. Obviously igneous rocks, and the crystalline rocks of the Archean or Basement Complex, whatever their origin, have yielded the materials for all later sediments, some of which have gone through several cycles of erosion and redeposition.

The development of a sedimentary rock from an igneous or crystalline rock involves redistribution of the materials, both minerals and elements. In the process of weathering, certain materials are taken into solution, while others are not. Of the materials not dissolved, some are removed by erosion as finely divided rock particles—mud, silt, and sand. The remainder consists of the partially weathered rock and residual clays which remain *in situ* where erosion lags behind such alteration.

The material transported in a solid state, upon deposition, forms the mechanical sediments of shales, sandstones, etc. Of the material carried in solution, a portion is deposited as cementing and vein-filling materials during the process of transportation. After reaching the sea, a part of the remaining material is precipitated, forming the chemical and organic sediments, the limestones, and other carbonates;

[1] This is the first of a series of articles on metamorphic problems to come from the Metamorphic Laboratory of the University of Wisconsin. The next title will be "The Metamorphic Cycle," by C. K. Leith.

and what is not precipitated remains in solution as part of the mineral matter of the sea.

The following table shows the general plan of redistribution:

TABLE I

GENERAL PLAN OF REDISTRIBUTION

Original Rock	Material removed	Carried as solids	Mechanical sediments (shales, sandstones, etc.)
		Carried in solution	Chemical sediments (limestones, etc.) Cementing materials Vein-filling materials Mineral matter of the sea
	Material remaining	....	Weathered rock Residual clays or earth

Various attempts have been made at quantitative estimates of the redistribution above outlined. Figures for the total thickness and relative amounts of the three classes of sediments have been obtained from actual measurement, but such estimates are confined to the present continental areas, taking no account of suboceanic deposits, and are limited to the comparatively small areas which have been studied by geologists. Several estimates have been made based on the nature and amount of material being carried to the sea by rivers, particularly on the ratio of calcareous to clastic sediments formed.

A few estimates have been made based either in part or entirely on chemical evidence. One of these has been made by Van Hise,[1] who has determined the relative amounts of shale, sandstone, and limestone on the basis of observed thickness, combined with chemical considerations, to be 65 : 30 : 5. Average chemical analyses of the shales, sandstones, and limestones were combined in the ratio of 65 : 30 : 5, respectively, and the resulting combination was found roughly to approximate the composition of the average crystalline rock.

A more recent estimate of the same ratio is one made by Clarke,[2] based on chemical evidence. This estimate is discussed on a later page.

[1] C. R. Van Hise, *A Treatise on Metamorphism*, Monograph No. 47, U. S. Geological Survey, 1904, chap. xi.

[2] F. W. Clarke, "The Statistical Method in Chemical Geology," *Proceedings of the American Philosophical Society*, Vol. XLV (1906), p. 21.

In the present paper the redistribution of the elements of the original crystalline rock will be taken up from a purely chemical standpoint. It will be the purpose to determine in what proportions the various sediments should be combined to yield an average composition most nearly like that of the original rocks from which they were derived, and to point out reasons for discrepancies which may develop.

We may look upon the table given on page 239 as an equation which may be written as follows:

$$\text{Original crystalline rock} + \text{Redistribution agencies} = \left\{\begin{array}{l}\text{Shales}\\ \text{Sandstone}\\ \text{Limestone}\\ \text{Vein-filling materials}\\ \text{Cementing materials}\\ \text{Salts of the sea}\\ \text{Residual matter}\end{array}\right.$$

If the several end-products making up the right-hand side of the equation could all be taken into account in proportion to their abundance, it is evident that the elements of the original rock would all be accounted for unless some minor factor has been overlooked. Of these end-products fair average chemical analyses are available for shales, sandstone, and limestone, and also for the salts of the sea. Of the vein-filling material very little is known in regard to abundance, and an average chemical analysis is impossible. Better, but still poor, results may be obtained from the residual materials. The cementing material is included in the analyses of the mechanical sediments. The sedimentary rocks form the major part of the mass of the secondary material, the other end-products being only a small percentage of the total mass; hence the proper combination of their analyses should approximate the original rocks—i. e., the left-hand side of the equation—even if the less important end-products be not counted, though their omission will cause certain discrepancies. Thus we may expect to find a deficiency of iron, owing to its segregation in iron formations and iron-ore deposits, which are not included in the analyses of the sediments. We may expect to find a deficiency of sodium, owing to the large amount of that element in solution in the sea.

Our purpose, then, is to ascertain in what proportions the sandstones, shales, and limestones should be combined to give the best

approximation to the average composition of the original igneous and crystalline rocks, making due allowances for the end-products other than sediments, not included in the combination.

DATA USED

There are only eight of the elements—oxygen, silicon, aluminum, iron, calcium, magnesium, sodium, and potassium—which compose more than 1 per cent. of the outer part of the lithosphere. The least plentiful of these, potassium, makes up about 2.3 per cent. of the lithosphere, while the next element in abundance, titanium, makes up only 0.4 per cent. The present discussion will be confined to the eight most abundant elements, which will be treated in the form of the following oxides: silica, alumina, magnesia, soda, and potassa. Iron will be considered in the metallic form, the sum of the metallic content of the ferrous and ferric oxides being taken in each analysis employed.

Perhaps the best determination of the average crystalline and igneous rocks yet available is one made by Clarke.[1] In obtaining this average the rock-forming elements were considered separately, each being averaged according to the actual number of determinations made. A group of truer estimates was thus secured than by averaging complete analyses together, as he had heretofore done. In the same bulletin (p. 21) are average analyses of the several sedimentary rocks. The average analysis of the shales represents an average of seventy-eight rocks carefully selected and weighted. Two determinations of the average composition of the sandstones are given. The average represents a composite analysis of 624 sandstones, equal weights being taken. For the average limestone Clarke gives two determinations—one a composite analysis of 345 limestones and the other a composite analysis of 498 limestones used for building purposes. For the present purpose an average of the two composite analyses was taken, representing an average of 834 limestones. The several analyses selected are given in Table II.

Most of the mass of the sedimentary rocks is derived from the crystalline rocks, but, in the process of redistribution, water and gases from the hydrosphere and atmosphere combine with the

[1] F. W. Clarke, *Bulletin No.* 228, U. S. Geological Survey, 1904, p. 17.

"derived" elements, either chemically or mechanically, and thus enter into the constitution of the sediments. These elements *not* derived from the crystalline rocks must be omitted from the analyses of the sediments before any quantitative estimates can be made on the redistribution of the elements of the crystalline rocks. In Table II the "underived" elements are marked with an asterisk, and the sum of the "derived" elements is given below. Omitting the "underived" elements, the analyses are recalculated on a basis of 100 per cent. totals which gives the analyses in Table III.

TABLE II

AVERAGE ANALYSES SELECTED FOR USE IN THE PRESENT DISCUSSION

	Av. Crystalline	Av. Shales	Av. Sandstone	Av. Limestone
SiO_2	60.48	58.38	81.76	9.64
Al_2O_3	15.17	15.47	5.37	1.28
Fe_2O_3	2.61	4.03	1.23	0.65
FeO	3.44	2.46	0.57	....
MgO	4.10	2.45	0.85	6.20
CaO	4.84	3.12	3.28	41.60
Na_2O	3.43	1.31	0.61	0.33
K_2O	2.96	3.25	1.24	0.45
*H_2O	1.89	5.02	1.69	0.97
TiO_2	0.72	0.65	0.33	0.07
P_2O_5	0.26	0.17	0.07	0.23
*CO_2	....	2.64	3.02	35.58
*S, SO, C	....	1.46	0.08	0.15
BaO and MnO	0.10	0.05	....	0.04
Total	100.00	100.46	100.10	100.19
"Derived"	98.11	91.34	95.30	60.49
"Underived"	1.89	9.12	4.80	39.70

TABLE III

"DERIVED" ELEMENTS OF TABLE II RECALCULATED TO 100 PER CENT. TOTALS

	Av. Crystalline Rock	Av. Shales	Av. Sandstone	Av. Limestone
SiO_2	61.60	63.90	85.72	15.94
Al_2O_3	15.47	16.96	5.63	2.12
Fe_2O_3	2.66	4.41	1.29	1.07
FeO	3.51	2.70	0.60	....
Fe	4.60	5.19	1.37	0.75
MgO	4.18	2.69	0.89	10.25
CaO	4.93	3.42	3.45	68.75
Na_2O	3.50	1.44	0.64	0.55
K_2O	3.02	3.56	1.29	0.74

METHODS USED

The problem now is to determine in what proportions the foregoing analyses of shales, sandstone, and limestone (Table III) should be combined so as to give an average analysis as nearly like that of the average crystalline rock as possible. "Cut and try" methods

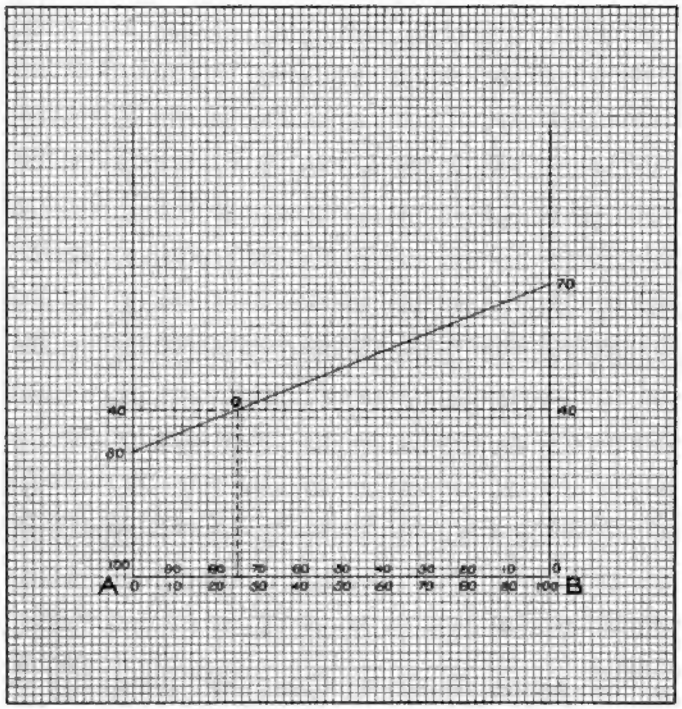


FIG. 1

are both tedious and unsatisfactory. A method of solution has been devised by means of which definite results may be obtained and the general conditions of the problem observed in perspective.

It will perhaps make an explanation of the method of solution clearer if the general principles are first applied to the simpler case of a combination of two analyses. Suppose, for example, it is desired to find out what proportions must be taken of two rocks, *A* and *B*, having respectively 30 and 70 per cent. of silica, to yield a combination that shall contain 40 per cent. of silica. Vertical distances in

Fig. 1 represent percentages of silica, and the two amounts of silica are plotted on the two vertical lines marked *A* and *B*, and the points connected by a straight line. This line represents by its ordinates the amount of silica in any possible combination of the two rocks, from 100 per cent. of one at one end to 100 per cent. of the other at the opposite end. To find what point on the line represents a combination containing 40 per cent. of silica, a horizontal line is drawn at a distance of 40 units from the base. Now, if the point *O*, at the intersection of the two lines, be projected vertically downward to the base, the percentages of the two rocks in the combination may be read at once; the figures above the base line representing percentages of A and those below the line percentages of *B*. It is seen that the combination is made up of 25 parts of *B* and 75 parts of *A*. In a similar manner it is possible to deal with each element in the rocks.

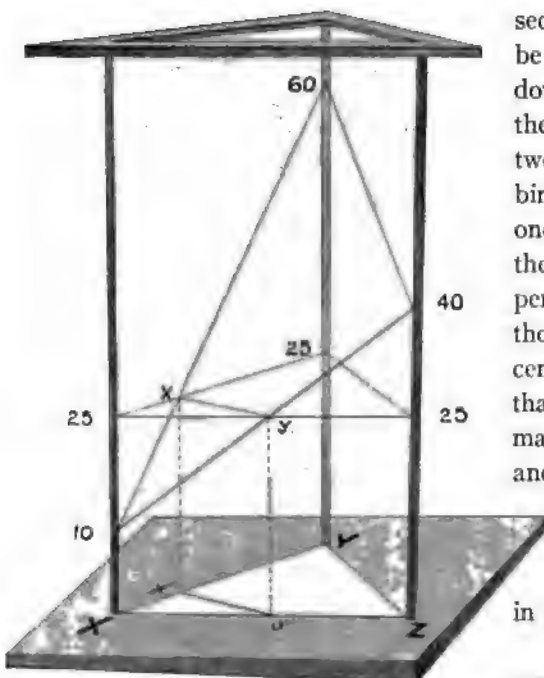


FIG. 2

To apply the same general principle to the case of the combination of three rocks: Suppose, for example, it is desired to ascertain what combination of three rocks, *X*, *Y*, and *Z*, having respectively 10, 60, and 40 per cent. silica, will contain 25 per cent. of silica. It is apparent at once that this problem cannot be considered in two dimensions, as was done in the case of a combination of two rocks; but the same general method may be employed by considering the problem in three dimensions. In Fig. 3 the three uprights are erected perpendicular to the base at the corners of an equilateral triangle. The

uprights correspond to the three rocks, X, Y, and Z, and are lettered accordingly. Vertical distances represent percentages of the elements as in Fig. 1. Points on the uprights representing percentages of silica are connected by a plane, instead of a line as was done in the case of the combination of two rocks. The ordinates of this plane represent any percentages of silica which may result from any possible combination of the three rocks. To ascertain what points in the

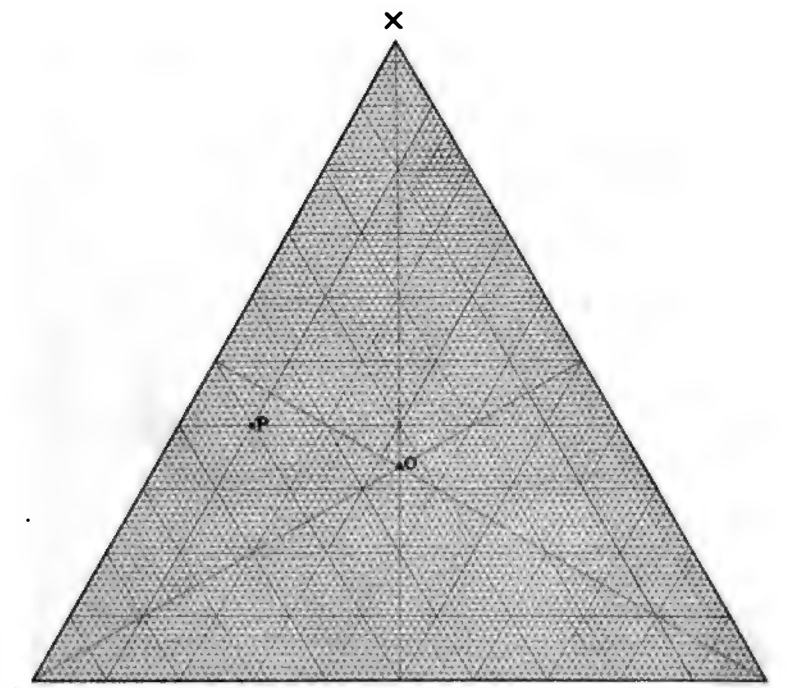


Fig. 3

plane represent 25 per cent. of silica, a plane is passed parallel to the base at a height of 25 units, and the line of intersection of the two planes contains all the points in the first plane which represent the desired 25 per cent. of silica. In the case of a combination of two rocks, as illustrated in Fig. 1, the ratios in which the two rocks entered into the desired combination was determined by projecting the point of intersection of the two lines onto the line at the base. In the case of a combination of three rocks, we have a trian-

gular surface at the base instead of a line. For this triangular surface a piece of triangular cross-section paper is used, like the one shown in Fig. 3. The three corners represent respectively 100 per cent. of *X*, 100 per cent. of *Y*, and 100 per cent. of *Z*. Any point in the triangle represents some combination of *X*, *Y*, and *Z*, and the percentage of each in the combination is measured by the distance

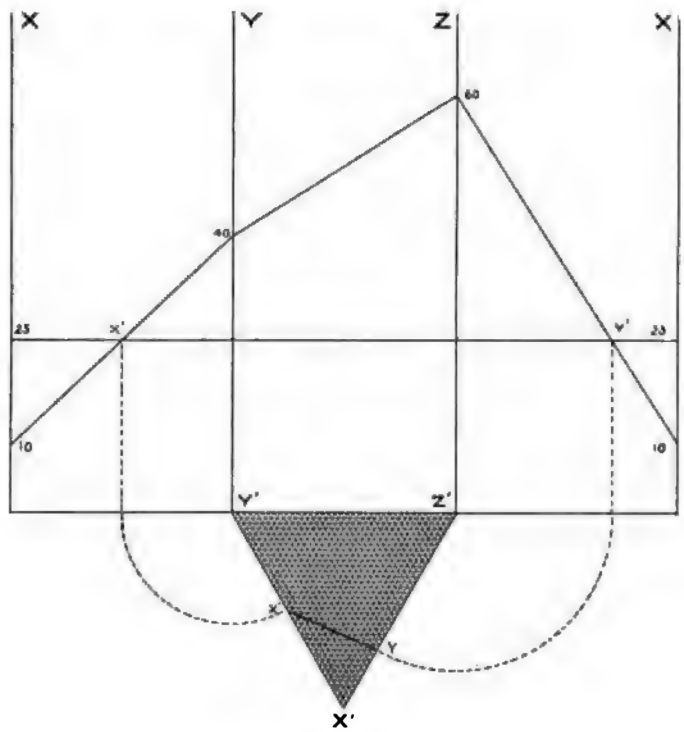


FIG. 4

between the point and the side opposite. To illustrate: the point P represents a combination made up of 40 per cent. *X*, 50 per cent. *Y*, and 10 per cent. *Z*. The point O in the center of the triangle represents a combination containing $33\frac{1}{3}$ per cent. of each of the three.

If the line of intersection of the two planes in Fig. 2 be projected vertically downward onto the base, it will represent all possible combinations of *X*, *Y*, and *Z* which contain 25 per cent. silica. By the same process the planes for the alumina content of the rocks may

be drawn and the line of intersection projected onto the base. This line will indicate all combinations of the three rocks which contain a certain percentage of alumina. The point of intersection of the silica line and the alumina line on the cross-section paper at the base indicates what combination of the three rocks contains the same amounts of silica and alumina as a given fourth rock. That is, we

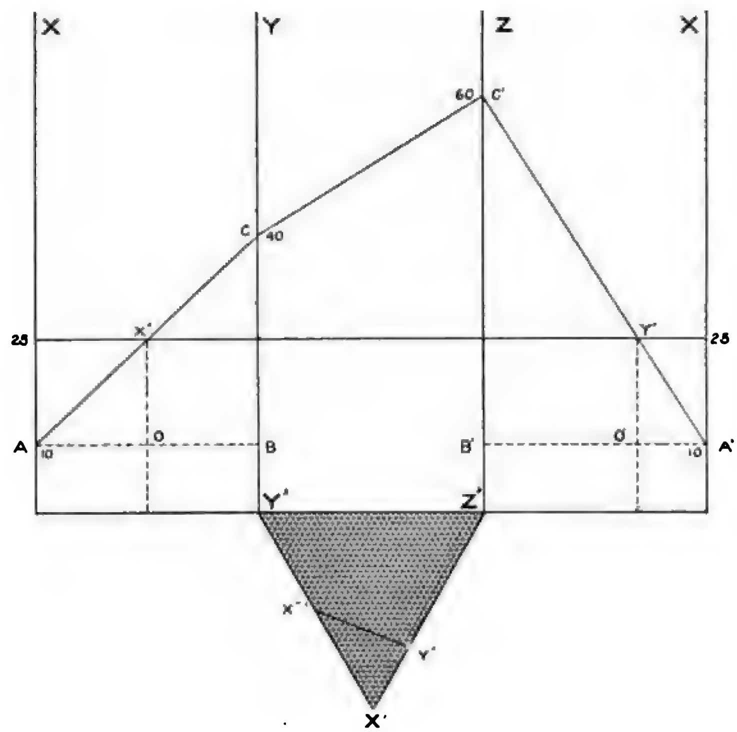


FIG. 5

have found out in what ratios X, Y, and Z must be taken to give a combination having the same content of silica and alumina as a given fourth rock. In the same manner this process may be continued to include the other rock-making elements, and, if the lines on the cross-section paper do not intersect at a common point, it is possible by inspection to determine the point which comes nearest to all of the lines, and thus we may determine what proportions of X, Y, and Z will make a combination which is as nearly like that of

a fourth rock as possible. An apparatus was constructed embodying the ideas shown in Fig. 2 and used in the solution of the problem. Silk threads were used for the edges and intersections of the planes, and to avoid confusion a different color was used for each component.

It was found, however, that more accurate results could be obtained by the following application of the principles involved in the apparatus. The three vertical planes are opened out flat, as shown in Fig. 4. The percentages are plotted as before, and intersections found at X' and Y' and projected down upon the base-line. The distances XY, YZ, and ZX correspond to the sides of the triangle, so the location of the points x and y is an easy matter. The problem admits of easy solution by this graphical method, but a very simple arithmetical solution is also possible which does away with the rather cumbersome details of a graphical solution and also admits of greater accuracy. In Fig. 5 the lines AB and $A'B'$ are drawn parallel to the base. In the left-hand side of the figure we have two similar triangles, ABC and AOx'. Hence $CB : AB :: x'O : AO$.

$$CB=40-10=30\,, \qquad x'O=25-10=15\,,$$

AB is equal in length to the sides of the triangle which is divided into 100 divisions, hence $AB=100$.

Substituting the values in the above proportion, we have,

$$30 : 100 :: 15 : AO\,.$$

From which, $AO=50$, and we see that the point x'' falls on the side $X'Y'$ of the triangle at a distance of 50 units from X'.

Considering the right-hand side of the figure, we have as before two similar triangles, $C'B'A'$ and $y'O'A'$, and we may write the following proportion,

$$C'B' : B'A' :: y'O' : O'A'\,,$$

$$C'B'=60-10=50\,, \qquad y'O'=25-10=15\,, \qquad B'A'=100\,,$$

substituting values in the above proportion,

$$50 : 100 :: 15 : O'A'\,,$$

solving,

$$O'A'=30\,.$$

We find that the point y'' falls on the side $X'Z'$ of the triangle at a distance of 30 units from X'.

RESULTS

The method of solution here described was applied to the four average analyses given in Table III, and the triangular diagram thus obtained is shown in Fig. 6. Since all the lines of the several elements in Fig. 6 do not intersect at a common point, some point must be selected which will give a minimum of discrepancies when the combination of the sediments is compared with the composition

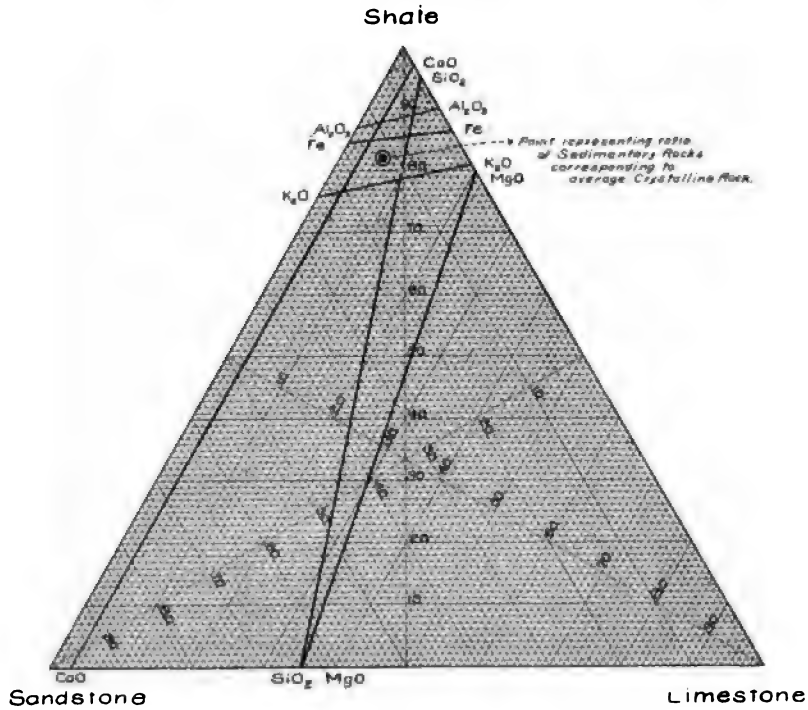


FIG. 6

of the average crystalline rock. A rough idea of what these ratios are may be obtained from a general inspection of the diagram, and it is seen at once that a point as near to all of the lines as possible lies near the "Shale" corner of the triangle and a little to the left, indicating a large predominance of shale and more sandstone than limestone. The two elements which have the greatest bearing on the selection of the best ratio are calcium and silicon, since these two elements are more unevenly distributed among the three sedi-

ments than any of the others, and any deviation from the best ratio will consequently produce greater discrepancies in calcium and silicon than in the elements which are more evenly distributed among the three sedimentary rocks. For this reason it is probable that the best point lies somewhere between the lime and silica lines. By referring to Table III it is seen that the shales contain more iron than either of the other classes of sediments, and hence a point above the iron line would indicate an excess of iron in the sediments and a point below it a deficiency. As we know that iron is segregated to a large extent in iron formations and ores, a deficiency is more probable than an excess, and the point evidently lies below the iron line. This throws it inside of the area bounded by the calcium, silica, iron, and potassa lines. A point at the center of this area gives a ratio of 82 parts shale, 12 parts sandstone, and 6 parts limestone, considering only such a part of the masses as is made up of the "derived" elements.

From Table II it is seen that the "derived" elements of the shales make up only 91.34 per cent. of the mass, of the sandstone only 95.30 per cent., and of limestone only 60.49 per cent. It is evident, then, that in the above ratio 82 represents only 91.34 per cent. of the total mass of the shales, 12 represents only 95.30 per cent. of the total mass of the sandstone, and 6 represents only 60.49 per cent. of the total mass of the limestone. If these figures are recalculated to take into account the entire mass of the sediments, we have as a ratio of shales, sandstone, and limestone, in even numbers, 80:11:9, respectively.

The relative abundance, then, of the three classes of sediments, as determined in the present investigation on the basis of average composition of crystalline rocks, is 80 parts shale, 11 parts sandstone, and 9 parts limestone.

The same process of solution was applied to a series of five average analyses of crystalline rocks,[1] ranging from acid to basic, and the same predominance of shale was observed in each case, ranging from 79 per cent. for acid rocks to 88 per cent. for the basic end of the series. This would seem to indicate that the redistribution of any crystalline rock results in a large predominance of shale in the

[1] Wright, *Tables of Igneous Rocks*, after Rosenbusch's classification.

resulting end-products. As would be expected, the ratio obtained from the average crystalline rock lies between those obtained for acid and for basic rocks; but it is noticed that the intermediate figure, 80 per cent., lies nearer the percentage of shale derived from acid rocks, 79 per cent., than that derived from basic rocks, 88 per cent. This indicates that in the group of analyses from which Clarke's average crystalline rock was obtained there was a considerable predominance of acid rock over basic rocks. This is in accord with the general opinion as to their relative importance.

DISCREPANCIES

In the following table the analyses of shales, sandstone, and limestone given in Table III have been combined in the ratios of 82:12:6, respectively, derived elements only being considered, and the resulting combination compared with the average crystalline rock.

TABLE IV

	Composition of Average Crystalline Rock	Average Analyses of Shales, Sandstone, and Limestone combined in the ratios of 82:12:6 respectively	Differences between the Composition of Av. Crystalline Rock and Comb. of Sediments
SiO_2	61.60	63.64	+2.04
Al_2O_3	15.47	14.71	−0.76
Fe	4.60	4.46	−0.13
MgO	4.18	2.90	−1.28
CaO	4.93	7.34	+2.41
Na_2O	3.50	1.29	−2.21
K_2O	3.02	3.12	+0.10

In the right-hand column the plus signs indicate an excess of that element in the sediments, and a minus sign indicates a deficiency.

While the sedimentary rocks form a very large proportion of the end-products of redistribution, it is evident that in considering only the sediments, as has been done in the solution of this problem, certain discrepancies may arise owing to the omission of the other end-products. These omitted end-products may account to a considerable extent for the discrepancies in Table IV. The most important of these omitted factors which admit at all of quantitative consideration are: mineral matter of the sea, the iron formations, and the residuary matter of the land. With a view of ascertaining to what extent the omission of these factors is responsible for the discrepancies

obtained, certain suppositions have been made regarding the composition and abundance, based on the best evidence at hand. Van Hise[1] estimates the average thickness of the sediments over the continental areas as 2 kilometers, or about 6,000 feet, and their total mass as 675,000,000,000,000,000 metric tons. This estimate is well in accord with Salisbury's[2] estimate of one mile for the thickness of the sediments. The salts of the sea, computed as oxides from Dittmar's determination, amount to a total mass equal to about 3.5 per cent. of the total mass of the sediments, as estimated by Van Hise. It is assumed that the average thickness of the residual mantle over the continental areas is 60 feet, or 1 per cent. of the total thickness of the sediments, and as a rough approximation the thickness of the iron formations, if spread uniformly over the continents, is 60 feet, or 1 per cent. For the chemical composition of the residual material an average was taken of several analyses of residuary materials given by Merrill.[3] For the average composition of the iron formations an average was taken of several hundred analyses of Lake Superior iron formations, weighting the ratio of iron-carbonate to iron-silicate rocks in the proportion of seven of the former to three of the latter. It is not assumed that the figures for composition and abundance here employed represent very closely the facts, but they are sufficient to show, in a rather broad way, the effect which a consideration of these minor end-products would have on the discrepancies arising.

TABLE V

	Comp. of Sediments 82:12:6 100%	Mineral Matter of the Sea. Calculated 3.5% of Sediments	Av. Comp. of Residual Material. Assumed 1% of Sediments	Av. Comp. of Iron Formations. Assumed 1% of Sediments
SiO_2	63.64	00.00	61.45	51.40
Al_2O_3	14.71	00.00	21.94	1.25
Fe	4.46	00.00	8.25	28.50
MgO	2.90	12.31	0.99	5.38
CaO	7.34	3.32	0.98	3.82
Na_2O	1.29	81.76	0.81	0.00
K_2O	3.12	2.64	1.84	0.00

[1] C. R. Van Hise, *A Treatise on Metamorphism*, Monograph No. 47, U. S. Geological Survey, 1904, p. 940.

[2] R. D. Salisbury, "Mineral Matter of the Sea," *Journal of Geology*, Vol. XIII, Septembler-October, 1905.

[3] G. P. Merrill, *Rocks, Rock-Weathering, and Soils*, p. 306.

In the foregoing table are given the compositions of the end-products of redistribution and their relative abundance.

In order to find the composition of the sum of the end-products, it is necessary to combine the above analyses in the ratios of abundance. In Table VI the result of this calculation is given and compared with the composition of the average crystalline rock.

TABLE VI

	Composition of Average Crystalline Rock	Comp. of Sediments 82:12:6	Diff.	Comp. of Combined End-Products	Diff.
SiO_2	61.60	63.64	+2.04	61.39	−0.21
Al_2O_3	15.47	14.71	−0.76	14.16	−1.31
Fe	4.60	4.46	−0.13	4.58	−0.02
MgO	4.18	2.90	−1.28	3.21	−0.97
CaO	4.93	7.34	+2.41	7.11	+2.18
Na_2O	3.50	1.29	−2.21	3.99	+0.49
K_2O	3.02	3.12	+0.10	3.06	+0.04

By comparing the two columns of differences in Table VI, it is seen that the sum of the differences arising when only the sedimentary rocks are considered is reduced by more than half by including the other end-products in the combination. The discrepancy for each of the elements except one is made considerably smaller. In the case of alumina the difference is increased from 0.76 to 1.31, but for each of the other components the differences are decreased. This very evident improvement in discrepancies would seem strongly to indicate that the discrepancies are to a large extent due to not including in the consideration of the problem all of the end-products of redistribution. It is not improbable that with better figures for average composition and abundance the differences would be reduced still more.

The close accordance between the composition of the combination of sedimentaries and the original crystalline rock, and the relatively small corrections produced by taking into account the other end-products, argues the probable correctness of the ratios determined, and also shows the relative unimportance of the minor end-products of redistribution.

COMPARISON WITH OTHER ESTIMATES

Van Hise estimated the relative abundance of the three sedimentaries as 65 parts shale, 30 parts sandstone, and 5 parts limestone.

In the following table are listed the discrepancies arising under Van Hise's ratio of 65:30:5 and the differences encountered in the present investigation.

TABLE VII

COMPARISON OF THE TWO RATIOS

	Diff. under Ratio of 65:30:5	Diff. under Ratio of 80:11:9
SiO_2	+3.2470	+2.04
Al_2O_3	−3.6800	−0.76
Fe	−1.1490	−0.13
CaO	(no discrepancy)	+2.41
MgO	−2.2025	−1.28
Na_2O	−2.4985	−2.21
K_2O	−0.2925	+0.10

The differences are less for the ratio of 80:11:9 than for 65:30:5. Van Hise's choice of ratio was influenced by estimates of observed thickness and relative proportions, and not alone by analyses.

Another estimate of the relative importance of the three classes of sedimentary rocks is one made by Clarke.[1] In attempting to ascertain the average composition of the lithosphere, he estimates it to be made up of 95 per cent. of igneous rock, with 5 per cent. of sediments, and he assigns 4.0 per cent. to be shales, 0.75 per cent. to the sandstones, and 0.25 per cent. to the limestones. This is equivalent to a ratio of shales to sandstone to limestone of 80:15:5, which accords rather well with the results of the present discussion. Clarke obtained his results by assigning all the free quartz of the average crystalline rock to the production of sandstone and half of the calcium of the average crystalline rock to the formation of limestone. The figure for free quartz was obtained from petrographical descriptions of about 700 igneous rocks.

The results of the present investigation are also roughly in accord with the results obtained from measurement of materials carried by rivers, but so many factors enter into such comparison that it will not be discussed here.

It is hardly to be expected that the relative abundance of the principal sedimentaries determined from field observations should

[1] F. W. Clarke, "The Statistical Method in Chemical Geology," *Proceedings of the American Philosophical Society*, Vol. XLV (1906), p. 21.

be in accord with the results obtained in the present investigation, which are based entirely on chemical evidence. This lack of accordance should not be interpreted as evidence that either of the ratios is incorrect. The figures obtained from field observations take into consideration only the present continental areas, and if it is assumed that they correctly represent the results of redistribution, it is also necessary to assume that the sedimentary formations at present on the continental areas constitute practically all of the redistributed material, or that sedimentation has been uniform over the earth's entire surface, in which case an average geological column for the continents would represent average sedimentation. The ratio based entirely on chemical evidence is not necessarily limited by the assumptions above mentioned, and for this reason it is believed that 80 per cent. shale, 11 per cent. sandstone, and 9 per cent. limestone is a better measure of the net results of redistribution than figures based on field evidence alone.

SUMMARY AND CONCLUSIONS

The sedimentary rocks are ultimately derived from the igneous and crystalline rocks. The general average composition of the sedimentary rocks should equal the average composition of the igneous and crystalline rocks, when minor corrections are made for the materials not classed as sediments, but derived from the same source, such as the salts of the ocean and ore deposits. The three main classes of sediments constitute fully 97 per cent. of the end-products of the destruction of the igneous and crystalline rocks. It should be possible to combine these three great groups in such a manner as to make them yield an average composition similar to that of the parent rock.

It has been the purpose of this investigation to determine the proportion which most nearly accomplishes this result. A quantitative method of solution has been devised which permits of ready and accurate solution of the problem.

The result has been found to be 80 per cent. of shales, 11 per cent. of sandstones, and 9 per cent. of limestones.

This proportion accords with that derived from other methods of

investigation in showing the striking dominance of shales in the sedimentary rocks.

The best available average analyses may not be correct, but the probable error, determined by noting the variations in the data available, is not so wide as to materially affect the result. It is believed that the proportion thus determined is entitled to more consideration than a proportion determined by measurement of field sections or of materials transported by rivers. If this proportion be not essentially correct, the best available average compositions vary essentially from the truth.

The small discrepancies between the composition of the parent rocks and the resultant principal groups of sedimentary rocks are found to be still further reduced when the relatively minute amounts of the minor end-products of the destruction of the parent rocks are taken into consideration.

The proportion of limestone determined (9 per cent. of the principal sedimentary rocks) is smaller than that obtained by measurement of geological sections. If the apparent difference is a real one—in other words, if the data which have entered into the two methods of calculation are reasonably correct—it may be concluded that there has been a concentration of limestone in the continental area. Whether this concentration is simply one of present areal distribution, the fragmental equivalents of the limestone at the present time being largely under the oceanic area, or whether the limestone has been uniformly concentrated through geological time in the upper part of the lithosphere, as has been held by certain writers, remains to be proved.

The work here outlined has been done in the metamorphic laboratory of the University of Wisconsin. I am greatly indebted to Dr. C. K. Leith for direction and criticism.

THE FORMATION OF LEUCITE IN IGNEOUS ROCKS

HENRY S. WASHINGTON

INTRODUCTION

In the following pages are presented the results of an attempt at the determination of the chemical characters of magmas which may control the formation of leucite in igneous rocks. Connected with this is an examination of the validity of the orders of affinity of the bases for silica and for alumina, which have been assumed as fundamental in the calculation of the norm in the quantitative classification. The paper is an extension of some previous studies, to be referred to subsequently, undertaken under the auspices of the Carnegie Institution. It may be pointed out here that the methods employed in the case of leucite are capable of application to other minerals.

I must express my deep obligations to my friends, Dr. Cross and Professor Iddings, with whom the first draft of this paper was discussed, for valuable suggestions in regard to the plotting of the diagrams and other matters, by which the work has gained much in simplicity and, it is to be hoped, in intelligibility.

It is commonly assumed or explicitly stated that the rocks in which leucite occurs are usually low in silica and high in alkalies, especially potash. But no definite limits for silica or for potash have been established, and leucite-bearing rocks are known which are quite high in silica and low in potash. Over forty years ago Roth[1] pointed out that the silica percentage of the rock could be either above or below that of leucite. Roth, in the last-cited work, and subsequently Zirkel,[2] observe that quartz does not occur with leucite, and the latter speaks of this as one of the few laws which can as yet be enunciated in regard to the mineral associations in igneous

[1] J. Roth, *Zeitschrift der deutschen geologischen Gesellschaft*, Vol. XVI (1864), p. 690; and also *Beiträge zur Petrographie der plutonischen Gesteine* (1869), p. 90.

[2] F. Zirkel, *Lehrbuch* (1893), Vol. I, p. 646.

rocks. He also notes the fact that leucite occurs more often in association with plagioclase than with orthoclase.

The characteristic occurrence of leucite in effusive rocks, and its absence from intrusive ones, have long been known, though recent observations have shown some undoubted exceptions to this latter statement. This general association is commonly attributed to the greater pressure under which the intrusive rocks have consolidated, and also in part to the presence of mineralizers, under which conditions leucite does not seem to be stable.[1] The possibility of potash entering the biotite molecule in combination with magnesia and ferrous oxide under certain circumstances, while under others this complex molecule does not form, but its constituents crystallize as leucite and olivine, has been pointed out and discussed by Lemberg,[2] Bäckström,[3] and others.

The general relations between the occurrence of leucite and the chemical characters of the rocks have been discussed by the authors mentioned above, as well as by others, among whom may be mentioned Iddings[4] and Lacroix.[5] These earlier discussions were largely qualitative, but in a more recent paper[6] Iddings discusses the chemico-mineral relationships of rocks from a mathematical standpoint, illustrated by diagrams, and much of the subsequent discussion is closely analogous to his. In these papers of Iddings the theoretical limits of some ideal magmas are pointed out, and the relationships of actual rocks to them are considered. Still more recently[7] Michel Lévy discusses mathematically the limits of the various magmatic divisions of the quantitative classification, with application to certain rocks, but without discussion of leucite.

[1] Cf. J. Lemberg, *Zeitschrift der deutschen geologischen Gesellschaft*, Vol. XL (1888), p. 635.

[2] J. Lemberg, *loc. cit.*, p. 636.

[3] H. Bäckström, *Geologiska Föreningens Förhandlingar*, Vol. XVIII (1896) p. 155.

[4] J. P. Iddings, *Bulletin of the Philosophical Society of Washington*, Vol. XII (1892), pp. 166, 176.

[5] A. Lacroix, *Enclaves des roches* (Macon, 1893), p. 637.

[6] J. P. Iddings, *Journal of Geology*, Vol. VI (1898), p. 219.

[7] Michel Lévy, *Bulletin de la Carte géologique de la France*, No. 92 (1903).

In a paper on the rocks of the central Italian volcanoes[1] the relationships of the leucitic and non-leucitic rocks, and the chemical characters of their respective magmas, were discussed with the view of throwing light on the chemical characters which controlled the formation of leucite in this region. Some general conclusions were reached, which will be referred to subsequently, and some of which seem to be of wider applicability. The present paper, as was mentioned above, is an extension of this study, the field being enlarged to include all known leucitic rocks. The theoretical limitations of leucitic norms are first determined mathematically on the basis of certain assumptions, and these are afterward compared with the actual facts as revealed by a study of the rocks themselves.

A great deal of work has been done in recent years by Morozewicz, Vogt, Doelter and his pupils, Day and Allen, and others, in determining the physico-chemical conditions involved in the formation of many of the rock minerals. While this work is of great value and importance, and highly suggestive in many ways, little reference will be made to it in the present paper, in which the more essentially chemical factors will be the main subject of investigation. This is partly because such an extension of the scope of our inquiry would unduly lengthen the paper, and partly because it is felt that such physico-chemical investigations, are not yet so complete and so detailed, especially as regards leucite, as to make their introduction, and the conclusions to be derived from them, satisfactory. They may and will be invoked in the future for the explanation of many of the facts set forth in the subsequent pages, but such an application here seems to be unjustified and rendered merely tentative by the paucity of our knowledge at the present time.

THEORETICAL DISCUSSION

While it is now well recognized that a given magma solidifying under different physical conditions may form very diverse mineral combinations, within the limits imposed by the chemical composition, yet for any given set of physical conditions it would seem that the relative affinities of the chemical constituents of the magma for

[1] H. S. Washington, "The Roman Comagmatic Region," *Carnegie Publication* No. 57 (1906), p. 181.

each other should determine the minerals actually formed. In accordance with the general facts of chemistry these relative affinities would vary more or less with differences in the physical conditions, such as temperature and pressure, and their influence may conceivably be altered by such factors as mass-action or the presence of catalyzers, bringing about different reactions between the constituents of the magma and the consequent formation of different minerals. But for igneous magmas in general, and within the comparatively narrow range of temperatures between the points where crystallization begins and the mass becomes solid, it will be permissible to assume certain general orders of affinity which should control in the great majority of cases, at least, and which a study of the minerals formed in holocrystalline igneous rocks would reveal to us.

Leaving out of account all of the (usually) minor chemical constituents, for the sake of simplifying the discussion, we may assume that rock magmas are composed of the oxides: silica, alumina, ferric oxide, ferrous oxide, magnesia, lime, soda, and potash. Whether these exist as such in the magma before solidification, or whether they are combined into more complex molecules, is an unsettled question, and one which need not concern us here. It is evident that a study of the relative affinities of each of these for the others would be very complex, but our knowledge of igneous rocks and of their component minerals clearly indicates that certain ones are of especial importance.

Of these the most important, and the one which most interests us, is that of the bases for silica, as silica is always present in the largest amount, and the great majority and the most abundant of the igneous rock minerals are silicates. While no universally applicable order of affinity can be established, for reasons given above, yet the well-known facts of mineralogy and the experimental researches of Lagorio, Morozewicz, and others, indicate the following as being the one which controls in the great majority of cases,[1] and the one which we may assume as fundamental in the present investigation. Beginning with the oxide which has the greatest affinity for

[1] Cf. Cross, Iddings, Pirsson, and Washington, *Quantitative Classification of Igneous Rocks* (Chicago, 1903), p. 192.

silica, this order is: potash, soda, lime, magnesia, and ferrous oxide. A second order of affinity of almost equal importance is that of the bases for alumina, usually the next most abundant constituent after silica. This order is the same as that for silica. Upon these are based very largely the calculation of the norm in the quantitative system of classification, that is, the simplest expression of the mineral molecules which experience has shown are most likely to be formed in igneous rocks.

On these assumptions the most important mineral molecules formed in the norm by each of the above five oxides may be referred to two pairs for each one, diopside being considered as split up into simpler molecules, and kaliophilite being disregarded on account of its excessive rarity. These pairs, one member of which has the highest and the other the lowest amount of silica, are as follows:

	Molecule	Base to Silica	Molecule	Base to Silica
Salic	Orthoclase, $KAlSi_3O_8$	1 : 6	Leucite, $KAlSi_2O_6$	1 : 4
	Albite, $NaAlSi_3O_8$	1 : 6	Nephelite, $NaAlSiO_4$	1 : 2
	Anorthite, $CaAl_2Si_2O_8$	1 : 2	Wanting	
Femic	Wollastonite, $CaSiO_3$	1 : 1	Akermanite, $Ca_4Si_3O_{10}$	4 : 3
	Enstatite, $MgSiO_3$	1 : 1	Forsterite, Mg_2SiO_4	2 : 1
	Ferrosilite,[1] $FeSiO_3$	1 : 1	Fayalite, Fe_2SiO_4	2 : 1
	Magnetite, Fe_3O_4	1 : 0		

Considering holocrystalline rocks alone, in accordance with these assumed orders of affinity of the bases for silica and for alumina, quartz would be formed only when there is an excess of silica over that needed to permit the existence of the higher silicated pair for each base present, when the lower silicated member would be absent. If there is insufficient silica for this, the potash will form orthoclase rather than leucite, the magnesia and ferrous oxide forming olivine rather than hypersthene, and soda forming nephelite rather than albite if necessary. On the basis of the assumed order of affinity for silica, melilite should be formed rather than nephelite; but it is found that this is not the case, melilite being notoriously much more rare than nephelite. This undeniable exception may be attributed (in great part at least) to the mass-action and the high stability of the complex pyroxene molecules, into which lime enters in preference to melilite. After the potash is satisfied, the soda would form albite

[1] Cf. Washington, *Professional Paper*, U. S. Geological Survey, No. 14 (1903), p. 90.

rather than nephelite, if there is silica enough, the magnesia and ferrous oxide remaining in olivine. Leucite should thus be formed only when there is insufficient silica for all of the potash to form orthoclase, even after all of the soda, magnesia, and ferrous oxide have been reduced to their lowest silicated conditions.[1] These relations are somewhat complicated by the presence of the diopside, magnetite, ilmenite, and other molecules; but, as they have been fully discussed elsewhere, further details are uncalled for.

The above-described behavior of the various oxides is the *normative* one; that is, the ideal result of the application of the assumed orders of affinity of the bases for silica and for alumina. It remains to be seen whether it is the *normal*[2] one or not; that is, whether the actual facts are in accordance with these assumptions, as regards the occurrence of leucite.

In this theoretical discussion we shall first consider the norms only, not the actual rocks, and we shall assume that there is neither an excess of alumina over the alkalies and lime (resulting in normative corundum), nor of alkalies over alumina (resulting in normative acmite or alkali metasilicates), so that alumina may be eliminated from consideration, as well as corundum, acmite, and alkali metasilicates. The possibility of the formation of kaliophilite will be disregarded, as well as the presence of such usually minor constituents as Cl, SO_3, TiO_2, P_2O_5, etc. The numerical relations of the various oxides will be expressed in the following pages as molecular ratios, so as to make them comparable chemically.

[1] It may be noted that, were the direction of affinity reversed, so that silica had an affinity for the bases, rather than the bases for silica, in the order named, the presumptive order of formation of the minerals would be the reverse of that described. On such a basis we would expect leucite to be formed in preference to orthoclase, then nephelite rather than albite, and hypersthene rather than olivine. On this assumption, therefore, leucite, nephelite, and hypersthene rocks should be more common than olivine ones, which is not the case, and leucitic and nephelitic rocks much more abundant relatively to feldspathic ones than these are known to be.

[2] On page 2 of the paper cited above Michel Lévy apparently considers that the term "normative" is synonymous with "normal," and he objects to it on the ground that the normative minerals are seldom normal ones. He has evidently overlooked our express statement of the distinction between the two words: "normative" being employed by us in the accepted English sense of "establishing or setting up a norm," while "normal" is recognized as having the meaning of "usual" or "common," and is therefore not used in this connection. (Cf. *Quantitative Classification* [1903], p. 147.)

The first problem before us, then, is the determination of the limits of variation in composition of all norms in which leucite does or does not occur in accordance with the principles laid down, and in holocrystalline rocks derived from which modal leucite should or should not be found. This problem is capable of exact mathematical statement and graphic expression.

As the simplest case we should consider first only the persalic, peralkalic, and perpotassic magmas—that is, those composed only of silica, alumina, and potash, the last two present in equal amount—so that the norms of these and holocrystalline rocks resulting from their consolidation would be composed either of quartz alone, quartz and orthoclase, orthoclase alone, orthoclase and leucite, or leucite alone. Such rocks are seldom met with, and their relations would be very simple. Furthermore, they form a limiting value of the next group to be discussed, so they will be dealt with later.

As the next simplest case we may assume that soda is present also in variable amount, the magmas being persalic and peralkalic, but the relations of the alkalies varying from perpotassic to persodic. On our assumption that potash has a greater affinity for silica than has soda, albite and leucite could not be present together in the norms, but these and the holocrystalline rocks derived from such magmas would be composed of quartz, orthoclase, albite, leucite, and nephelite, either alone or in all possible combinations, with the exception just stated. The general chemical composition of such magmas will be represented by the following equations:

$$aSiO_2 + bAl_2O_3 + cNa_2O + dK_2O = 100$$
$$Al_2O_3 = Na_2O + K_2O$$

The variables here are the absolute amounts or percentages of silica, soda, and potash, and the ratios of silica to soda, silica to potash, and soda to potash. Any two of these may be selected as a basis for plotting, and in my paper on the rocks of the Roman comagmatic region the percentage of silica was used for the abscissas, and the ratio $\frac{SiO_2}{K_2O}$ for the ordinates. Indeed, all the data represented on Plates I and II have been plotted on these bases, Plate III being the equivalent, thus plotted, of Plate I, as will be discussed later.

This use of ratios which may vary from zero to infinity, however, leads to hyperbolic curves, complicating the relationships and introducing very serious and misleading distortion through the extension of the diagram to infinity in one direction, and is therefore disadvantageous.[1] Consequently, and at the suggestion of Dr. Cross and Professor Iddings, this basis of plotting has been abandoned, and the percentage of silica used for the abscissas and the percentage of potash for the ordinates, both being expressed molecularly. While the relation of silica to potash, an important factor in the question of the formation of leucite, is thus rendered not quite so evident, yet the diagrams gain in simplicity and intelligibility, and there is also the great advantage of dealing only with straight lines, thus immensely simplifying the calculations and the construction, as well as the comparison of the actual rocks with the theoretical data.

The calculation of any given magma is readily carried out by means of the equations already employed for the calculation of the center-points.[2] The results will be given in Table I at the end of this paper. Plotting these data for our assumed peralkalic and persalic magmas, with variable amounts of soda and potash, we obtain the results shown in Plate I. In this the solid lines are those passing through magmatic center-points, and the broken ones those passing through the border-points of the magmatic divisions. The purely sodic magmas lie along the bottom of the diagram, while the purely potassic ones are at the top. One hundred per cent of silica is at the left and zero at the right, as this is in accordance with the diagrams of Iddings and facilitates comparison with them. Furthermore, this corresponds with the order in which the various divisions are arranged in the *Quantitative Classification.*

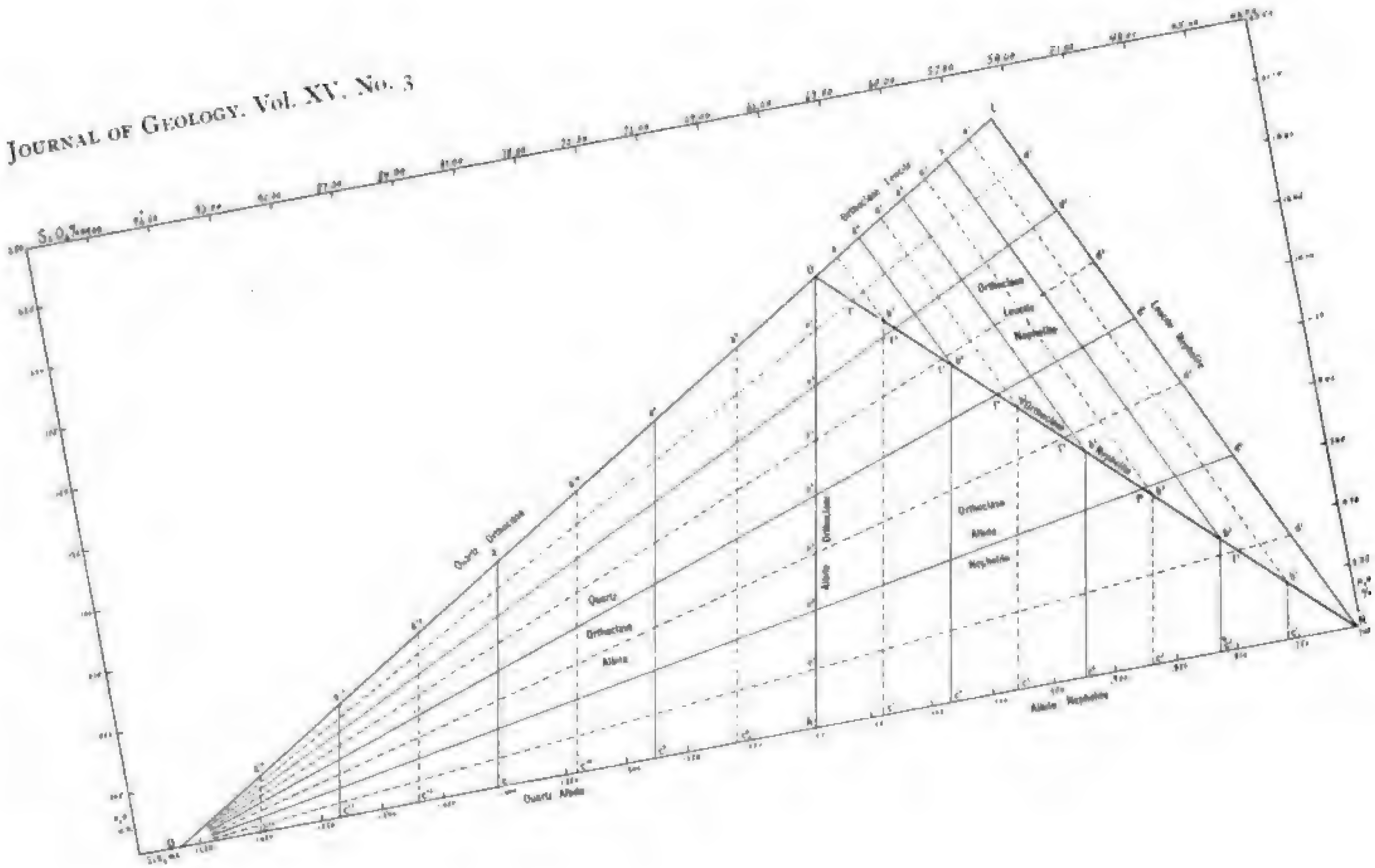
It will be observed that these lines resemble those of Iddings[3] in some respects. The latter, however, employs for the ordinates the ratio $\frac{K_2O+Na_2O}{SiO_2}$, instead of the percentage of potash, and conse-

[1] Cf. Michel Lévy, *Bulletin de la Carte géologique de la France*, No. 92 (1903), p. 25.

[2] H. S. Washington, *Professional Paper*, U. S. Geological Survey, No. 14 (1903), pp. 84–87.

[3] J. P. Iddings, *Journal of Geology*, Vol. VI (1898), Plates IX and X; and *Professional Paper*, U. S. Geological Survey, No. 18 (1903), Plate II.

JOURNAL OF GEOLOGY. Vol. XV. No. 3



quently obtains curves instead of straight lines. Furthermore, Iddings' first diagrams were constructed before the elaboration of the magmatic divisions of the quantitative system, so that the center-points and border-points of these are not considered, while in his later diagram the limits are given for the orders and rangs of potash-lime and soda-lime rocks, the alkalies being considered separately.

It may be pointed out that all such diagrams represent loci of chemical equilibrium, the lines or curves being those of definite combinations of the chemical or mineral constituents. They are analogous to the pressure-temperature, concentration-temperature, and other diagrams employed to represent physico-chemical equilibria. It may also be noted that, apart from considerations of simplicity, convenience, or intelligibility, it makes no difference whether ratios or percentages are chosen as bases for plotting. The relations will be evident in either case.

Turning to Plate I, the line LN is the locus of norms composed wholly of leucite and nephelite, passing through the center-points of the various subrangs of order 9 in a persalic and peralkalic magma. Pure leucite is found at L and pure nephelite at N. Between these extremes are varying mixtures of the two, the points for definite combinations, which correspond to the center-points and border-points of the subrangs, being indicated by the intersections with the solid and broken lines which slope down toward the left. To the right of or above this line no peralkalic and persalic norms can exist, since there will be insufficient silica to satisfy the alkalies unless kaliophilite is formed, and this molecule has been excluded from consideration. To the left of or below it there will be an excess of silica, so that either orthoclase or albite or both will be present.

The line OA is the locus of purely feldspathic norms, that is of the center-points of order 5, composed wholly of orthoclase and albite in varying proportions, pure orthoclase being found at O and pure albite at A, and the definite combinations which correspond to the center-points and border-points of the subrangs being indicated by the intersections with the solid and broken lines which extend upward toward the right. To the right of this line the norms must contain nephelite or leucite, or both of these, the maximum amounts being reached at the leucite-nephelite line LN, along which lenads alone

are found. To the left of the orthoclase-albite line OA there is an excess of silica over that needed for the feldspars, so that the norms must contain quartz.

Connecting O and L is the line LO, which is the locus of purely potassic norms (the ordinal center-points of subrang 1), consisting of varying amounts of orthoclase and leucite, from pure orthoclase at O to pure leucite at L. Below this line soda is present, forming either albite or nephelite, or both, while above it no norms can exist, for the reason to be mentioned presently.

Although irrelevant to the immediate discussion, the line OQ may be mentioned. This is continuous with LO, and is the locus of norms composed only of orthoclase and quartz in varying proportions, orthoclase occurring at O and quartz at Q. Above and to the left of this orthoclase-quartz line, as well as its continuation OL mentioned above, no norms can exist, since, for any given point in this region, the sum of the silica, alumina, and potash will be greater than 100 per cent if alumina and potash remain equal, or, if the necessary alumina is excluded, the potassium metasilicate molecule will be present, and this we have excluded from consideration. To the right of and below this line the norms will contain increasing and varying amounts of albite and nephelite, and decreasing amounts of quartz, until the orthoclase-albite line OA is reached, when quartz vanishes and to the right of which nephelite enters into the norm.

Within the area LOAN, therefore, are to be found all norms composed only of orthoclase, albite, leucite, and nephelite. The purely potassic ones will lie along the leucite-orthoclase line LO, and those richest in leucite toward the top of the area around the point L, while the purely sodic ones will be found along the albite-nephelite line AN, the albitic ones being around the point A. As albite and leucite cannot coexist in the norm, *ex hypothese*, it is clear that in one part of the area LOAN leucite must be present without albite, while in another part albite will be present without leucite, in each case in combination with varying amounts of orthoclase and nephelite.

The line separating these two is the line ON, which is the locus of norms composed only of orthoclase and nephelite in varying amounts, from pure orthoclase at O to pure nephelite at N. To the left of this the norms contain orthoclase, albite, and nephelite, but no

leucite; while to the right of it they contain orthoclase, leucite, and nephelite, but no albite.

This orthoclase-nephelite line ON is therefore a highly important one in our discussion, marking, as it does, one limit of leucitic norms, the others being the leucite-nephelite and leucite-orthoclase lines LN and LO, beyond which no norms can exist, as we have seen above. Within the leucite-orthoclase-nephelite area LON, therefore, must fall all leucitic peralkalic and persalic norms, and this may be called the *leucitic area*. Several features of this leucitic area deserve remark as bearing on the subsequent discussion. The first is the small size as compared with the feldspar-nephelite area OAN and the feldspar-quartz area OQA. Calling the area of the leucitic area of LON unity, that of OAN is 1.662, and that of OQA is 1.966. Or expressed in percentages of the whole area LQN they are as follows: LON = 21.61, OAN = 35.91, and OQN = 42.48.

The second feature is the shape and the position of the leucitic area—an acute-angled, almost isosceles, triangle, with the apex down and inclined sharply to the right. In consequence of this shape and position, the greatest variation in potash occurs at the silica percentage of leucite, $S = 0.9194$, and the greatest variation in silica at the potash percentage of orthoclase, $K = 0.180$. Therefore, as the percentage of silica of the magma falls below that of leucite, the possible range in potash rapidly diminishes till the silica percentage of nephelite is reached at $S = 0.704$, while as the percentage of silica of the magma rises above that of leucite the range in potash diminishes at a more rapid rate until the silica percentage of orthoclase is reached, above which no leucite can exist.

Crossing the whole area LQN are seen two sets of lines, one representing the loci of the center-points and border-points of the orders, and the others the center-points and border-points of the subrangs. The lines $a^1b^1c^1$, $a^2b^2c^2$, etc., are the loci of the different ratios of lenad to feldspar and of feldspar to quartz, corresponding to the center-points and border-points of the orders. The ordinal lines $a^1b^1c^1$ to $a^7b^7c^7$ are broken at the intersections b^1, b^2, etc., with the orthoclase-nephelite line ON, the lower limiting value of the leucitic area, while a^9c^9 to $a^{16}c^{16}$ are straight and continuous. This change in direction or refraction in passing out of the leucitic area follows

mathematically from the change in the norm. Starting from the top, where the magmas are perpotassic, increase in soda necessitates an increase in the amount of nephelite, this being the only sodic mineral present, and orthoclase being the only feldspar possible within the leucitic area. This brings about a decided decrease in the silica percentage, as that of nephelite is much less (42.25) than those of orthoclase (64.75) and leucite (55.05). On the other hand, left of the orthoclase-nephelite line ON, where the potash enters only into orthoclase and the relative amount of nephelite remains constant along the ordinal line, increase in soda necessitates an increase in the amount of albite. This causes a rise in the silica percentage, since that of albite (68.70) is higher than that of orthoclase (64.75).

The other set of lines, $d^1f^1e^1Q$, $d^2f^2e^2Q$, etc. are the loci of different ratios of potash to soda, corresponding to the border-points and center-points of subrangs. Since along these subrang lines the relation of potash to soda remains constant and the variation is in the amount of silica, an increase in silica causes an absolute decrease in the amount of potash, expressed by a slope of the line to the left. They are therefore straight and continuous, vanishing at the left in the point Q, which is the locus of pure quartz.

A study of the sizes and forms of the various areas included between the dotted lines corresponding to the limits of the various magmatic divisions of persalane (except the rangs, those here represented being all peralkalic) is of interest as showing the differences between these and their possible normative characters in different directions. But this is apart from our subject, and would lead us too far astray.

We have been dealing so far only with persalic and peralkalic magmas, in which only quartz, orthoclase, albite, leucite, and nephelite can form. But it is well known that such rocks are extremely rare, plagioclase feldspars and femic minerals entering into the norms of nearly all igneous rocks to a greater or less extent. To render our theoretical data adequately comparable with actual rocks, therefore, we must consider magmas which contain salic lime, and an equal amount of alumina, furnishing anorthite, and those which contain femic molecules, in both cases with varying amounts of silica and alkalies. It is clear that it would be a very complicated undertaking

to examine these fully, owing to the many combinations possible and the almost unlimited number of choices in the matter of variables, especially when the femic minerals are considered. But fortunately the calculation and presentation of a large number of hypothetical magmas is not necessary, and the general principles can be readily shown by a few typical cases.

Still adhering to persalanes, we may introduce anorthite and examine domalkalic and alkalicalcic magmas, that is, those in which the total alkalies are respectively, three times the amount of lime, and equal to it, corresponding to the center-points of the second and third rangs. The norms of these would contain quartz, orthoclase, albite, anorthite, leucite, and nephelite, in all possible combinations and amounts, except that albite and leucite would never occur together. These are represented on Plate II.

In Plate II the black lines represent the loci of persalic magmas, the green those of dosalic magmas, and the red those of salfemic ones. The orthoclase-quartz line OQ, and the feldspar-quartz area OQA, have been omitted as irrelevant to the discussion, but it is to be remembered that these quaric areas are always to be understood as existing, even though unrepresented. Also the lines which express the relations of feldspar to lenad (orders) and of potash to soda (subrangs) are omitted, as their presence would complicate the diagram with little compensating advantage. The dotted lines A^1L^1 and L^1M will be referred to subsequently. The small squares and circles represent the positions of actual rocks, and will be referred to subsequently. In the pages which follow, letters in italics, as *LON* for instance, indicate homologous points, lines, and areas in general, without specification of any particular kind of magma.

The solid black lines, marked L^1, O^1, etc., are the loci of persalic and *peralkalic* magmas, which have been treated above, and these are identical with the corresponding ones on Plate I. The black lines made up of long dashes, and marked L^2, O^2, etc., are the loci of persalic and *domalkalic* magmas; while those composed of short dashes, and marked L^3, O^3, etc., belong to persalic and *alkalicalcic* magmas.

Comparison of these three systems reveals some interesting relationships. The leucite-nephelite lines L^1N^1, L^2N^2, etc., and the ortho-

clase-nephelite lines O^1N^1, O^2N^2, etc., are very close together and parallel, this being due to the fact that in nephelite and in anorthite the relative number of molecules of silica to those of soda and of lime is the same in both(2 : 1),while the molecular weights of soda and of lime (62 and 56), and consequently of nephelite and of anorthite (284 and 278), are approximately the same. These lines, however, shift successively to the left or more siliceous end of the diagram with the introduction of the anorthite molecule, since the silica percentage of this is slightly higher than that of nephelite, 43.17 and 42.25 respectively.

On the other hand, the introduction of the anorthite molecule reduces the amount of potash present, so that the lines L^2O^2 and L^3O^3 are successively lower than the peralkalic line L^1O^1. They are also shifted successively toward the right or less siliceous end, owing to the low percentage of silica in anorthite. L^2O^2 and L^3O^3 are not parallel to L^1O^1, since they are continuous with the lines O^2Q and O^3Q, not shown in the diagram, these perpotassic borders ending in the common point Q. It will also be seen that the lines O^2A^2 and O^3A^3 are successively lower and more to the right than O^1A^1, this following from the considerations mentioned above.

It will also be of interest to examine the relative sizes of the various areas, the quaric areas *OQA* being also considered, as of possible interest, though not pertinent to the present discussion. The size relations are shown in the two succeeding tables, the first showing the relative sizes referred to the corresponding peralkalic area as unity, and the second in percentages of the whole area LQN.

It will be seen that, while the leucitic areas become successively smaller with increasing lime, yet that relatively to the feldspathic areas, *OAN*, they remain practically constant; this last relationship being due to the very slight shift in the diagram toward the left of the lines *LN* and *ON*. It will also be seen that, as lime enters, the leucitic area decreases, as does the feldspathic area, but that the quaric area increases, relatively to the whole amount of possible magmas.

All the above relations will, of course, be the same in direction, though differing in amount, if the magma is assumed to be docalcic, while if it be percalcic the areas will vanish in the point SiO_2 =

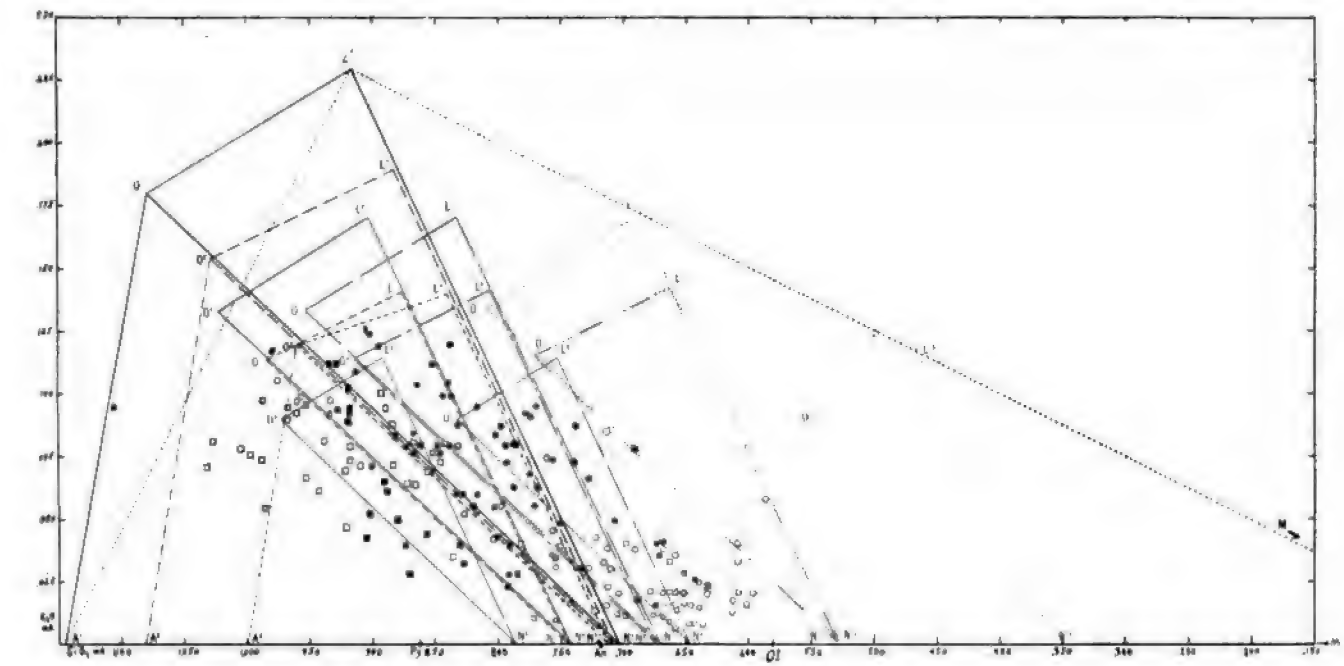


TABLE I

RELATIONS OF HOMOLOGOUS AREAS, REFERRED TO THE PERALKALIC AREA AS UNITY

Area	Peralkalic	Domalkalic	Alkalicalcic
LON..............	1.000	0.731	0.417
OAN..............	1.000	0.724	0.434
OQA..............	1.000	0.962	0.855
LQN..............	1.000	0.827	0.609

TABLE II

RELATIONS OF HOMOLOGOUS AREAS, IN PERCENTAGES OF THE AREA *LQN*

Area	Peralkalic	Domalkalic	Alkalicalcic
LON..............	21.61	19.11	14.78
OAN..............	35.91	31.45	25.60
OQN..............	42.48	49.44	59.62
LQN..............	100.00	100.00	100.00

0.719, along the abscissal axis, this being the molecular amount of silica in anorthite. This is also the point of intersection of lines drawn through L^1, L^2, etc., and through O^1, O^2, etc., with the line QN. Consequently all persalic leucitic norms will lie in the area L^1O^1An N^1.

From the above we may draw the following conclusions as to the influence upon the leucitic area of the introduction of anorthite into the magma. The possible range in potash for any magma with a percentage of silica greater than that of the corresponding mixture of leucite and anorthite will be decreased, while for silica percentages below this point there will be but little change. For homologous magmas, as regards order and subrang, the absolute amount of potash will decrease, while that of silica will also decrease down to a certain point, dependent on the magma, after which it will slowly rise.[1] As the amount of anorthite increases, the size of the leucitic area decreases, both absolutely and relatively to that of the whole area of possible norms, this decrease being increasingly great.

It is therefore clear that, in general, the introduction of anorthite into persalic magmas has little influence on the presence of leucite

[1] Compare the figures on p. 95 of *Professional Paper* No. 14, U. S. Geological Survey, 1903. Those for the more lenic orders are incomplete, as the compositions of the more calcic rangs of these, which cannot exist according to the definition of the respective orders, were not calculated.

in the norm, except when they are highly potassic, or unless the amount of salic lime exceeds that of the alkalies, when its influence will be increasingly felt.

We may now introduce femic molecules into the magma and see what influence they exert upon the presence of leucite. In order not to complicate the calculations unduly, we shall examine only a few simple, but typical, cases.

Let us first assume that the femic mineral is a standard, non-aluminous pyroxene exactly intermediate between diopside and hedenbergite—with MgO = FeO, and the formula $Ca (Mg, Fe)(SiO_3)_2$. The molecular weight of this is 232, and its silica percentage is 51.72, intermediate between that of orthoclase and those of nephelite and anorthite. We shall also assume that the magmas are centrally dosalic and salfemic—that is, with the amount of salic minerals in the norm three times that of the femic, and equal to it respectively. In the case of the dosalanes we may also consider the two cases in which the magma is either peralkalic or domalkalic. The variable factors then will be the relations of feldspar to lenads and of potash to soda, as in the previous cases. The lines which limit the leucitic areas in these norms are shown in Plate II, the peralkalic and domalkalic dosalanes respectively by solid and short-dashed green lines, and the salfemic magmas by solid red lines. The orthoclase-albite lines (*OA*) are omitted, as unnecessarily complicating the diagram. They may be drawn in, if desired, from the points *O* to *A*, parallel to the lines O^1A^1, O^2A^2, and O^3A^3.

Confining our attention, therefore, to the leucitic areas alone, it is evident that these are all identical in shape with those of the persalanes which are homologous as regards salic lime. The lines L^4N^4, L^5N^5, and L^6N^6 are parallel to L^1N^1, L^2N^2, and L^3N^3, and similarly the lines *ON* are all parallel to each other. On the other hand, the peralkalic L^4O^4 and L^6O^6 are parallel to the peralkalic L^1O^1, while the domalkalic L^5O^5 is parallel to the domalkalic L^2O^2.

With increasing amounts of pyroxene, the several leucitic areas become smaller, until they would vanish (for peralkalic magmas) in the pure assumed pyroxene at the point Py, where $SiO_2 = 0.862$ on the line QN, which is also the intersection point of lines drawn through the homologous points L^1, L^4, and L^6, and O^1, O^4, and O^6. Fur-

thermore, the areas are shifted successively toward the more siliceous end of the diagram, owing to the higher percentage of the pyroxene in silica than in nephelite, It will also be noted that the influence of the introduction of anorthite is exactly similar in character to that already noted in the case of the persalanes, though the change is less quantitatively, as shown by the lines L^4N^4 and L^5N^5, and O^4N^4 and O^5N^5, being closer together than was the case with the homologous lines in the persalanes. But it seems needless to go into greater details, as the principles will be the same as with the preceding cases.

We may next assume that the femic molecule is an olivine, exactly intermediate between forsterite and fayalite—that is, with $MgO = FeO$. The molecular weight of this is 172, and the silica percentage is 35.88. As in the preceding case, we shall consider both dosalic and salfemic magmas, and in the former shall assume the magmas to be peralkalic and domalkalic, while in the salfemanes only peralkalic ones will be considered. Pyroxene is assumed to be absent in all these cases.

The leucitic areas of these various olivinic magmas are shown in Plate II, the peralkalic and domalkalic dosalanes respectively by green lines made up of very long dashes and of the same with alternating short ones, while the salfemic magmas are represented by red lines made up of very long dashes. Here again the triangular leucitic areas are of exactly the same form and parallel to the homologous ones in the persalanes and the pyroxenic magmas, and, furthermore, the sizes of the olivinic areas are the same as those of the corresponding pyroxenic ones. Thus, $L^7O^7N^7$ is the same size as $L^4O^4N^4$, and $L^9O^9N^9$ as $L^6O^6N^6$, and so on. This, of course, is due to the fact that the relative amounts of potash in homologous magmas remains the same whether olivine or pyroxene is introduced. But it will be seen that the introduction of olivine, rather than pyroxene, shifts all these leucitic areas well toward the right, or less siliceous, end of the diagram, a consequence of the lower silica percentage of the olivine. Furthermore, as in the preceding cases, increase in the amount of olivine lessens the size of the triangle until, for perfemic magmas, they would vanish at the point Ol, where $SiO_2 = 0.598$ in the line QN, which is the locus of our assumed olivine, and which is also the intersection of lines passing through L^1, L^7, and L^9, and

through O^1, O^7 and O^9. Here also the influence of the introduction of anorthite is similar to that observed in the preceding cases, in the olivinic as in the pyroxenic salfemanes the lines LN and ON respectively falling so close together, in the otherwise homologous cases, as to be indistinguishable unless the diagram is drawn on a much larger scale than that used here.

Finally, we may introduce molecules of magnetite (without either pyroxene or olivine) into peralkalic and domalkalic dosalanes and peralkalic salfemanes. The leucitic areas of these are shown respectively by green lines made up of dots, and of dots and short dashes, and by red lines made up of dots. Here the shift toward the right or less siliceous end of the diagram is very pronounced, owing to the entire absence of silica from the femic mineral.[1] But the triangles are of exactly the same sizes as in the homologous cases just studied, and the homologous lines are all parallel. Furthermore, the leucitic areas become smaller and smaller absolutely with increase in magnetite, until they vanish at the point M, where $SiO_2 = 0$, the locus of non-siliceous magmas, which lies to the right and outside of the diagram.

In the preceding cases we have assumed magmas of definite compositions, corresponding to certain center-points in the quantitative classification, as well as femic mineral molecules of simple and definite compositions and introduced singly. But it is clear that greater or less admixtures of anorthite or of femic molecules, or the introduction of several femic molecules simultaneously, will influence the positions of the various loci to a greater or less extent, but always in directions similar to those indicated by the examples given. Thus, if pyroxene and olivine, or pyroxene and magnetite, or all three, were assumed to be present in different proportions, the positions of the corresponding leucitic areas would lie between those of purely pyroxenic and purely olivinic or magnetitic ones, corresponding to the salic content, the exact position depending on the relative amounts and the compositions of the minerals present.

But in all cases—and this point is of great importance in the subsequent discussion when we come to deal with actual rocks—homolo-

[1] Apatite, ilmenite, corundum, or any other non-siliceous mineral would have, of course, the same effect as magnetite.

gous lines would be parallel to each other. Thus, the lines *LN* would be parallel to those here given, as would be the lines *ON* parallel to the lines *ON* of the diagram. It follows from this that the acute angle *LNO* of all possible leucitic areas would be the same, and also that the angles *LNM*[1] and *ONQ* would also be constant, so that the inclination of the triangular leucitic areas as regards the abscissal line QM would always be the same.

On the assumption that the kaliophilite molecule is excluded, it is also evident that all possible rock magmas must fall within the large triangle L^1QM, since outside of and above it there will be too much potash, as explained on a previous page (p. 272), and the points Q and M respectively represent pure quartz, or 100 per cent of silica, and pure non-siliceous mineral, or 0 per cent of silica.

As regards the sizes of the various leucitic areas, it is clear that, while they decrease absolutely with increase in anorthite or femic molecules, yet that relatively to the areas *OAM*, *OQA*, *LQN*, *LNM*, and *LQM*, corresponding in the relative amount of anorthite in any given case, they remain constant. This follows geometrically from the parallelism of the sides of the various homologous areas. Thus the ratio of the size of the salfemic and magnetitic leucitic area $L^{12}O^{12}N^{12}$ to the whole area $L^{12}Q^{12}N^{12}$ is the same as that of the persalic leucitic area $L^1O^1N^1$ to the whole area $L^1Q^1N^1$, since their homologous sides are parallel.

In general, therefore, the influence of the presence of anorthite and of standard, non-aluminous pyroxenes is to lower the percentage of potash without greatly disturbing the percentage of silica, or, in other words, to raise the ratio of silica to potash for the leucitic areas; while the presence of olivine molecules tends to lower this ratio to a less extent, the change being nil in the case of magnetite, and also to diminish to a much greater degree the percentage of silica in the magma, this reaching a maximum with magnetite.

In consequence of these relations, and those discussed in the preceding paragraphs, while with increase in femic minerals the leucitic areas extend on the whole toward the non-siliceous end of the diagram, so that eventually they cover the whole area to the right of the

[1] M is used to indicate the locus of magnetite where $SiO_2=0$ and $K_2O=0$, as explained above.

line O^1N^1, yet for any given set of magmas, homologous as regards the relative amounts of anorthite and given femic minerals, and variable only as regards feldspars and lenads and soda and potash, and consequently with fixed limits (*LQN*) for all possible magmas, there will be no disturbance of the ratios of the normatively leucitic ones and those normatively free from leucite.

From the above discussion and study of the diagrams, and on the assumption that potash has a greater affinity for silica than has soda or any other of the bases, we may draw the following conclusions as to the relations between the chemical composition of the magma and the formation of leucite, which are to be tested later by comparison with the data furnished by actual rocks.

1. There should be no leucitic rocks with an excess of silica over that necessary to bring all the bases to their highest silicated condition —that is, leucite should not occur in rocks whose norms show the presence of normative quartz.

1*a*). As a corollary to this we should never expect to find modally leucitic rocks with a silica percentage greater than 64.75, that of orthoclase; and as femic minerals and anorthite enter into the magma, the silica percentage of possible leucitic rocks should never exceed that of a mixture of orthoclase with the appropriate amounts of anorthite and femic minerals.

2. On the other hand, we can expect to find leucitic rocks with silica percentages running down to zero as a limiting value.

3. We should expect to find the greatest range in the percentage of potash consistent with the presence of leucite, and consequently the greatest number of leucitic rocks, with silica percentages about equal to those of mixtures of leucite and the appropriate amounts of anorthite and femic minerals. From these maxima the range in potash and the number of leucitic rocks should diminish slowly as silica falls, and should diminish more rapidly as silica rises.

4. We should not expect to find rocks without normative leucite carrying this mineral in the mode, and conversely we should expect rocks with normative leucite to carry this mineral modally.

4*a*). As a corollary to this it follows that, if the locus of a rock, expressed in terms of the percentages of silica and potash, and plotted as on Plate II, falls within the leucitic area corresponding to its char-

acters as regards anorthite and femic minerals, it should have leucite in the mode; while, if it falls outside of this area, it should be modally free from this mineral.

5. From the relative sizes of the leucitic and non-leucitic areas we should expect leucitic rocks to be much less abundant than non-leucitic ones.

6. We should not expect the presence of femic molecules in the magma to exert much influence on the presence of leucite, while the presence of anorthite should tend to lessen the probability of its presence, this influence being increasingly felt as the magma becomes more calcic.

Consequently we could expect to find leucitic rocks with very large amounts of femic molecules, but should not expect to find them with large amounts of salic lime, that is, when the amount of this exceeds that of the alkalies.

7. Other things being equal, there should be more probability of a rock being leucitic the higher the potash, while with increase in soda as regards potash the tendency toward the formation of leucite should diminish rapidly, so that we should not expect to find many leucitic rocks with soda in excess of potash.

There are given on Plate III the results of the data for persalic and peralkalic magmas plotted with the abscissas representing percentages of silica (but with 100 per cent to the right), and with the ordinates representing the ratios $\frac{SiO_2}{K_2O}$. Otherwise it is analogous to the diagram on Plate I. It is introduced because it is explanatory of my previous study of the subject, where this method of plotting was adopted, and because it is illustrative of the complexity introduced by the adoption of ratios rather than percentages as a basis for plotting, while the general relationships are still manifest. A brief description must suffice.

The lettering, and the signification of the lines and areas, on Plate III are the same as on Plate I; only it must be borne in mind that the directions, both up and down and right and left, are reversed, and that non-potassic and purely sodic magmas and normative minerals lie above the diagram at infinity, a serious distortion being thus introduced.

The line LN is that of pure lenad, leucite and nephelite, pure leucite being found at L and pure nephelite where the curve touches its asymptote[1] at infinity and where $SiO_2 = 0.704$. The line OA is that of pure feldspar, orthoclase being found at O, and albite where the curves become tangent at infinity with its asymptote at $SiO_2 = 1.145$. The curve LO is that of perpotassic magmas (leucite-orthoclase), and is continuous with the curve OQ, that of quartz and orthoclase, quartz being found at the point where the curve touches its asymptote at infinity and where $SiO_2 = 1.667$. The curve ON^1 is that of orthoclase and nephelite, orthoclase being found at O and nephelite where the curve touches its asymptote at infinity and where $SiO_2 = 0.704$, N and N^1 coinciding here.

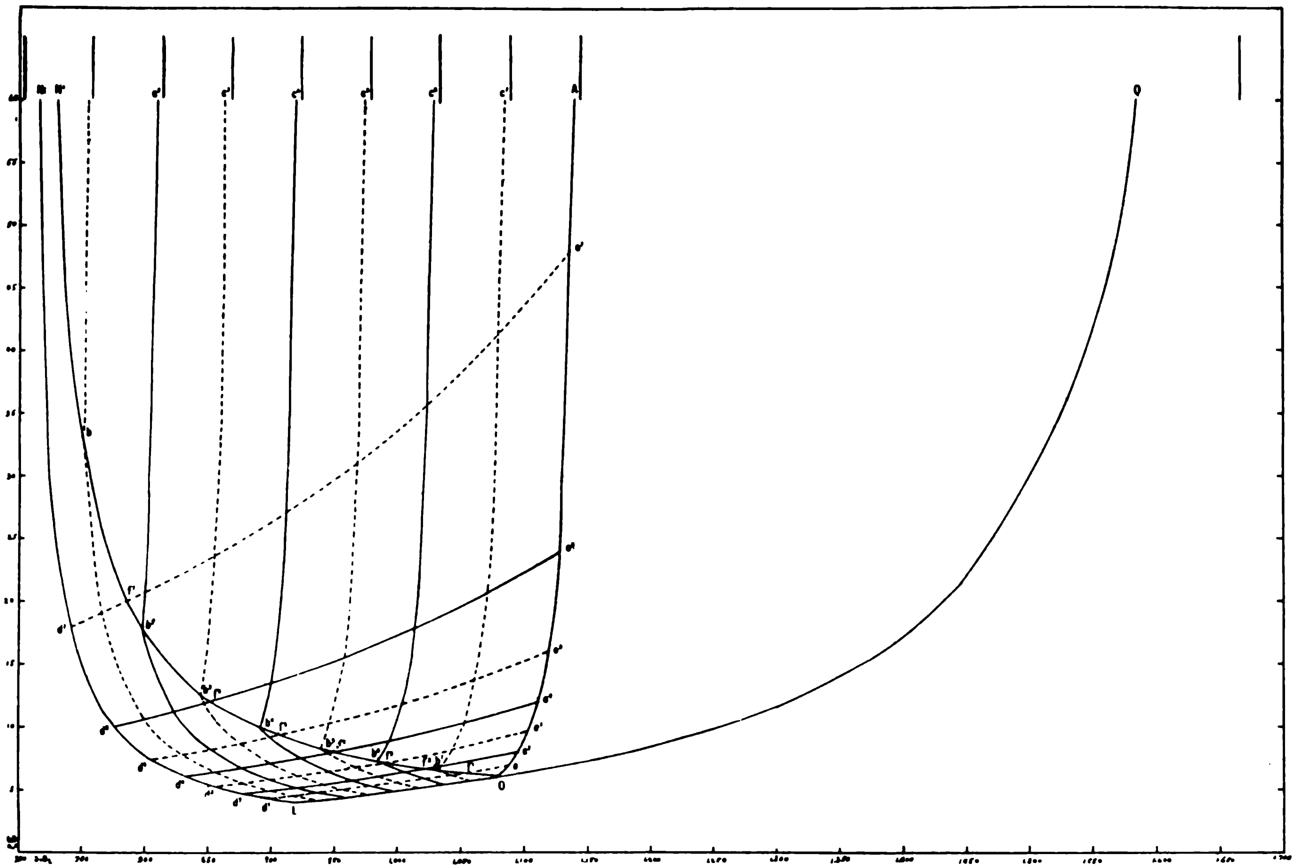
The leucitic area is therefore bounded by the curves LN, LO, and LN^1, N and N^1 rising and approaching each other with decreasing potash till they coalesce as just explained. The area N^1OA is that of orthoclase-albite-nephelite; and AOQ is that of quartz-orthoclase-albite, both of these extending upward to infinity. The whole area NLOQ, therefore, embraces all possible magmas, since outside of it no norms can exist, as already explained.

The ordinal curves are shown running down the diagram from top to bottom, and with well-marked cusps where they meet the orthoclase-nephelite curve N^1O, the angle of the cusp decreasing as the magma becomes more lenic. This change in direction is due to causes already explained. The curves representing subrangs run across the diagram from left to right. They are all continuous, but become successively steeper with increase in soda, for reasons referred to in a previous page.

Introduction of anorthite and of various femic minerals yield exactly similar homologous curves and areas, which have all been plotted, but which are omitted here. Their influence is quite analogous to that observed on Plate II. Thus the introduction of anorthite causes the curve LO to rise and shift successively toward the left with increasing lime, while the curves NL and N^1O are shifted to the right, but remain very close to each other.

But further description is unnecessary, and it may merely be

[1] The positions of these fixed asymptotes are indicated by the short straight lines at the top of the diagram.



pointed out that all the relations observable on Plates I and II, where the curves resolve themselves into straight lines, are fully manifest on a diagram plotted on this basis, though not so readily intelligible, owing to the distortion introduced.

APPENDIX I

Loci of Leucitic Areas of Various Magmas

No.	Character of Magma	O	L	N	
1....	Peralkalic persalane	1.079 .180	.917 .229	.704 .000	SiO_2 K_2O
2....	Domalkalic persalane	1.028 .154	.883 .189	.708 .000	SiO_2 K_2O
3....	Alkalicalcic persalane	.959 .120	.840 .140	.712 .000	SiO_2 K_2O
4....	Peralkalic dosalane, with diopside	1.025 .135	.904 .172	.744 .000	SiO_2 K_2O
5....	Domalkalic dosalane, with diopside	.986 .116	.877 .142	.746 .000	SiO_2 K_2O
6....	Peralkalic salfemane, with diopside	.971 .090	.890 .115	.783 .000	SiO_2 K_2O
7....	Peralkalic dosalane, with olivine	.955 .116	.833 .142	.673 .000	SiO_2 K_2O
8....	Domalkalic dosalane, with olivine	.916 .116	.807 .142	.676 .000	SiO_2 K_2O
9....	Peralkalic salfemane, with olivine	.830 .090	.749 .115	.643 .000	SiO_2 K_2O
10....	Peralkalic dosalane, with magnetite	.809 .135	.688 .172	.528 .000	SiO_2 K_2O
11....	Domalkalic dosalane, with magnetite	.771 .116	.662 .142	.531 .000	SiO_2 K_2O
12....	Peralkalic salfemane, with magnetite	.540 .090	.459 .115	.352 .000	SiO_2 K_2O

[*To be continued*]

THOMAS CONDON

CHESTER W. WASHBURNE
Chicago

The death (February 11, 1907) of Professor Thomas Condon ended a life little known among scientists, yet a life of considerable service to geology.

Professor Condon was an unusual man in that he seemed to have no desire to publish the results of his study. There are but few papers, only eight strictly geological, and one book, published over his name. But the writings of the scientists of his day—Le Conte, Dana, Marsh, Cope, and others— are full of references to Dr. Condon, and all of them acknowledge his contribution to science by exploration and theory.

Condon discovered the famous John Day beds which have so enriched our knowledge of Tertiary vertebrates. Here he found some of the specimens of three-toed horses on which Marsh based his theory of the evolution of that animal.[1] In this instance Marsh gave the discoverer scant credit for his work, and the type-specimens remained in Yale Museum until after Marsh died. The same thing happened to many other valuable specimens loaned to Marsh, Cope, Gabb, and others. A fine lot of Pliocene birds from southeastern Oregon, loaned to Cope, were never returned. It was doubtless to the interest of science that these fossils fell into the hands of other men, but it was unjust to Condon not to acknowledge more fully his services, and not to return his specimens. In 1867 Professor Condon printed in the *Portland Oregonian* an account of what he then thought to be the first fossil-horses found in America, the same specimens that Marsh described several years later. What a strange contrast between these zealous, ambitious paleontologists, and that lonely, unselfish but no less devoted worker in the wilderness of Oregon!

Condon's best friend and occasional companion was Joseph Le Conte, who accompanied him on several trips, and who always gave

[1] Professor Henry F. Osborn has said: "I believe that Professor Condon deserves the entire credit of the discovery of the Upper Oligocene horses in the John Day." (*Pacific Monthly*, November, 1906, p. 566.)

him the fullest credit when publishing his ideas or observations. These two old lovers of earth-science recall a comparison made by Suess,[1] in writing of an almost unknown geologist, Arnold Escher von der Linth:

> On the one side stood Sir Charles,[2] the calm, superior philosopher, the lucid thinker and able writer; on the other, dear old Arnold Escher, who intrusted his admirable sketches and diaries to everyone indiscriminately, but to whom every line he had to publish was a torment, and who was perhaps only quite in his element up in the snow and ice, when the wind swept his gray head and his eye roamed over a sea of peaks.

From a scientific standpoint Professor Condon's best contribution is doubtless his paper[3] on "The Willamette Sound." Condon showed that this Pleistocene body of water filled the Willamette Valley, and extended north to Puget Sound, with a probable length of about three hundred miles. He worked out its extent and depth by means of terraces along the Columbia River and the ocean.

Professor Condon's book, *The Two Islands*,[4] is a popular account of the geological history of the original "Oregon country." The Klamath mountain group of southwestern Oregon and northern California was an island (Siskyou Island) in the Cretaceous sea, separated from the Sierra Nevada by Diller's Lassen Strait. The Blue Mountains, however, were not an island (Shoshone Island) at the time, for only in the Upper Cretaceous (early Chico) did the sea reach even the western part of the Blue Mountain region. But Condon's treatment of the subject brought out the striking geological difference between the two mountain groups and the rest of the state, showing that they are two regions of Paleozoic and Mesozoic rocks surrounded by Tertiary lavas and sediments.

Thomas Condon was born in Ireland, March 3, 1822. When he was eleven years old, the family moved to New York City; later to the central part of New York state, where Condon finished his education, taught school, and made a collection of New York paleozoic

[1] Preface to *Das Antlitz der Erde*, translation by Hertha Sollas.

[2] Sir Charles Lyell.

[3] "The Willamette Sound," *Overland Monthly*, Vol. VII, No. 5, pp. 468–73 (San Francisco, 1871); Reprinted as a chapter in *The Two Islands*.

[4] *The Two Islands and What Came of Them*. (Portland, Ore.: The J. K. Gill Co., 1904.)

fossils which later formed the nucleus of his splendid collection at the University of Oregon. He graduated from Auburn Theological Seminary in 1852, married Miss Cornelia Holt, and sailed for Oregon by way of Cape Horn.

For several years he had charge of the Congregational Mission at The Dalles, Oregon, then a small trading-post. It was while stationed at The Dalles that Condon made most of his trips into the interior, generally with military parties, gathering the fine Tertiary mammals in his collection. In 1872 he became professor of geology and natural history at Pacific University, resigning in 1876, to accept the same chair in the newly created University of Oregon. Here he remained until 1905, confining his teaching in later years mainly to paleontology. In these last years Professor Condon was too feeble to go into the field, but he had become so well known that people in all parts of the state were constantly sending him new specimens, knowing well the pleasure these gifts brought to the old naturalist who no longer could gather them himself. They were fresh links to the outdoor world, to the scenes of his early activities that he so enjoyed in memory.

Condon was one of those rare men that study science from an inherent love of nature, not merely for self-advancement, or for the praise of men.

BIBLIOGRAPHY

"The Willamette Sound." *Overland Monthly*, Vol. VII, No. 5, pp. 468–73. (San Francisco, 1871.)

Preliminary Report of the State Geologist [of Oregon]. 22 pages. (Salem, Ore., 1874.) Abstract in *American Journal of Science*, Third Series, Vol. IX (1875), p. 401.

"Washington Territory" [and Oregon] (geological formations). Macfarlane's *American Geological Railway Guide*, 1879, pp. 172, 173.

"On Some Points Connected with the Igneous Eruptions along the Cascade Mountains of Oregon." *American Journal of Science*, Third Series, Vol. XVIII (1879), pp. 406–8.

"Oregon." Macfarlane's *Geological Railway Guide*, second edition (1890), pp. 316, 317.

The Two Islands, and What Came of Them. (Portland, Ore.: The J. K. Gill Co., 1902.)

"The Ice Caves of Mount Adams." *Mazama*, Vol. I, pp. 102, 103.

"A New Fossil Pinniped from the Miocene of the Oregon Coast." *Bulletin of the University of Oregon*, May, 1906; supplement to Vol. III, No. 3. Review by J. Wortman, *Science*, N. S., Vol. XXIV (July 20, 1906), pp. 89–92.

AEGIRITE AND RIEBECKITE ROCKS FROM OKLAHOMA

AUSTIN F. ROGERS
Stanford University, California

Several years ago the writer spent a short time in studying and collecting the igneous rocks of the Headquarters Mountains in Oklahoma. An examination of the rocks some time afterward revealed the presence of aegirite and riebeckite, minerals which at the present time can scarcely be called rare, but are very interesting. Other occurrences of riebeckite in this country are: (1) granite of Quincy, Mass.;[1] (2) pegmatite of St. Peter's Dome, Colorado;[2] (3) paisanite, Paisano Pass, Texas.[3]

The Headquarters Mountain group comprises several low mountains at the extreme western border of the Wichita Range. The largest lies adjacent to and northwest of the town of Granite, Greer County, Oklahoma. There are several further to the northwest and a single one a little southeast of the town, all being west of the North Fork of the Red River.[4] These mountains like the others of the Wichita Range to the east rise abruptly from the level plain which give them an archipelago character.

THE COUNTRY ROCK

The main mass of these mountains is made up of a coarse-grained red granite. It weathers to large, rounded bowlders. Fresh specimens are very difficult to obtain as the ferro-magnesian constituents are almost invariably altered. The average size of the constituent minerals is about 7^{mm}. Under the microscope the rock is seen to be made up of orthoclase, albite, quartz, amphibole and zircon. The

[1] Washington, *Am. Jour. Sci.*, Vol. VI (1889), p. 180.

[2] Lacroix, *C. R.*, Vol. CIX (1889).

[3] Osann, *T. M. P. M.*, Vol. XV (1896), p. 437.

[4] For location see map, Plate II (opposite p. 54), "Professional Paper No. 31." *U. S. Geol. Surv.* On p. 58 of this paper a paragraph is given to description of this group of mountains. They are said to consist of red granite similar to that of the Wichita group.

orthoclase is intergrown with albite with characteristic twin lamellae appearing around the border or in the interior, thus forming microperthite, which is a characteristic feature of the rocks of this locality. An occasional Carlsbad twin occurs. The quartz is full of very minute inclusions. The amphibole is a dark-colored one with the following axial colors: $\mathfrak{a}$, brown, $\mathfrak{b}$, deep greenish-blue, $\mathfrak{c}$, deep bluish-green. The extinction angle on (110)[1] is about 25°. The elongation is parallel to slower ray. It has the 124° cleavage of amphibole. Doubtless it is a soda amphibole, perhaps nearer hastingsite than any described mineral. Several small zircon crystals were discovered in the fragments of the crushed rock. Biotite was also noticed in some of the rock.

GRANITE-PORPHYRY, MICRO-GRANITE, ETC.

About half of the number of rock varieties collected are included under this heading. They grade from coarse granites with porphyritic tendency to fine-grained micro-granites, and are usually reddish or reddish-gray in color.

These fine grained micro-granites weather into rather angular bowlders.

The rocks are aggregates of quartz and orthoclase (often microperthite) with accessory amphibole, biotite, magnetite and apatite. The amphibole is sometimes riebeckite, sometimes one resembling that of the country rock. A rather peculiar intergrowth of quartz and orthoclase was noticed in one rock (No. 3). It may be described as an orthoclase mosaic in quartz. The quartz areas have uniform extinction over quite large areas, while the orthoclase areas only have uniform extinction over small areas. Thus it is neither a micropegmatitic nor micropoikilitic growth. One of the micro-granites occurs on the top of Mt. Walsh, the highest point of the Headquarters group. It is but a few feet thick and a little way down the slope the contact between it and the coarse granite may be seen.

APLITE VEINS

Perhaps the most interesting rocks of the region are the narrow dikes that cut the coarse granite, the country rock. About seven or

[1] Determined on cleavage flakes.

eight of these occur near the center of the largest mountain just northwest of Granite. They vary in width from one to sixteen inches. The prevailing color is a greenish-gray inclined to reddish-gray in places. The rocks are fine-grained with equidimensional constituents averaging about 1^{mm} in diameter. With a lens glassy grains of quartz, cleavable feldspars, black prismatic crystals (riebeckite), usually small but sometimes 3^{mm} in length, and minute greenish patches and needles (aegirite) can be recognized.

In thin sections these rocks are seen to be fine-grained mosaics of quartz, microperthite, and accessories with the typical panautomorphic texture of aplites. Both the feldspar and quartz have a tendency to assume a crystal form. The microperthite is an intergrowth of cloudy orthoclase with clear albite which is recognized by extinction angles and index of refraction. The albite occurs in patches within the orthoclase, on its border and in a few cases, independently. The orthoclase often occurs in Carlsbad twins. The quartz is xenomorphic to automorphic in various specimens. The best automorphic quartzes were hexagonal in outline though only a few of these were basal sections. The riebeckite, one of the accessory minerals usually occurs in large patchy aggregates so characteristic for this mineral, but in one rock (No. 12) it was in the form of small grains. Its color varies from green through a bluish-green and greenish-blue to deep, almost opaque blue. The axial colors are $\mathfrak{a}$, very deep blue; $\mathfrak{b}$, deep blue; $\mathfrak{c}$, green. $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$. The extinction is practically parallel. In addition to cleavage parallel to (110), parting parallel to (010) was noticed. The aegirite varies from minute needles to small prismatic crystals with the octagonal cross-section characteristic of the pyroxenes. The pleochroism is yellowish-green to emerald-green, and the maximum extinction 5 or 6°. Magnetite and microcline are found in small amount.

The order of consolidation seems to have been first, the orthoclase, then the albite, next the aegirite and finally the quartz. The aegirite occurs as inclusions in the quartz (but not in the orthoclase), but mostly between the quartz and orthoclase. In one rock (No. 44) aegirite needles occur with their long axes parallel to outlines of the quartz. In this case it looks as though the quartz had simply pushed aside the aegirite, as there is no constant orientation due to

crystallization. Apparently the more abundant the aegirite is, the more abundant the albite.

An interesting case of alteration was found in one of the veins. Specimens of a vein some distance apart were collected before they were discovered to be the same rock. One of these (No. 44) was a fresh rock, greenish-gray color, with abundant crystals and needles of aegirite. The other specimen (No. 23) was gray with a dead look. The aegirite had disappeared and abundant magnetite had formed at its expense. The outlines of the aegirite crystals were filled with magnetite dust, and there were many large magnetite grains and crystals all through the rock.

RIEBECKITE PEGMATITE

At the foot of Main Street, in the town of Granite, near the base of the mountain, a pegmatite vein six and one-half inches (16^{cm}) wide was found. It occurs in the coarse granite and has a nearly east-west strike with dip toward the north. The striking thing about this rock is the occurrence of prismatic crystals two or three centimeters long and $\frac{1}{2}^{cm}$ in diameter. They have the six-sided cross-section of the amphiboles, and often appear with a central core of orthoclase. The other minerals are quartz, orthoclase and a little albite. The rock has the typical vein structure, for at the center is a band of fine-grained rock, on either side a zone of coarse-grained rock, and then on each side at the contact with the wall rock there is a band of fine-grained rock. Each of the bands is about 3^{cm} wide, but the vein is not quite symmetrical.

DIABASE DIKE

A short distance east by northeast of Mt. Walsh a fine-grained, black, basic dike, about four and one-half feet wide occurs. It has an east-west strike and almost vertical dip. The rock is exposed in a prospect shaft and is much altered. It consists of lath-shaped plagioclases, amygdules filled with a chlorite-like mineral (representing original ferro-magnesian mineral), and abundant magnetite. The rock has the typical ophitic structure, and so is a diabase.

An interesting thing about this dike is that it can be traced across the mountain by the character of the vegetation, though the rock is only exposed in one spot. The vegetation on the mountain is very

scant, but along the "lead" of this dike the vegetation is very abundant and a narrow strip of shrubs extends across the mountain.

These rocks are mostly soda rich as shown by the presence and comparative abundance of microperthite (orthoclase-albite), aegirite, riebeckite, and another soda amphibole of doubtful identity. A study of these rocks in connection with those of other parts of the Wichita mountain system, especially if chemical analyses were available, would probably give some very interesting results.

STUDIES FOR STUDENTS

THE RECENT ADVANCE IN SEISMOLOGY

WILLIAM HERBERT HOBBS
University of Michigan

I. THE DISTRIBUTION OF SEISMICITY IN RELATION TO THE EARTH'S MOBILE BELTS

Introduction.—It is entirely safe to say that no period of equal length has registered so great an advance in the science of seismology as the decade now just brought to a close. The more important developments of this period may be broadly stated under three heads: (1) the determination of the laws of distribution of seismicity; (2) the discovery of a method for sensing and locating macroseisms through the body of the planet; and (3) the accumulation of so large a body of observational data as to advance from the condition of vague speculation to a well-grounded theory of the cause of earthquakes.

The laws of distribution of seismicity have been determined by a French officer of artillery, Count de Montessus de Ballore, whose thorough and conscientious work has occupied almost a lifetime. Rudolph had already, in 1887, made a most important contribution to the subject in a series of papers upon the distribution of seaquakes and submarine volcanic eruptions, which are supplementary to the studies by de Montessus. The discovery of new methods for studying at a distance the greater world-shakings is to be attributed, perhaps more than to anyone else, to the veteran English seismologist, Professor John Milne, who first started the great movement in Japan for seismological investigation, and since his return to England has been generously supported by the British Association for the Advancement of Science. The most modern and thoroughly equipped earthquake station today is, however, the German Chief Station for Earthquake Investigation at Strassburg, long directed by Professor Gerland, the founder of the International Seismological Association and the editor of its admirable

journal, *Gerland's Beiträge zur Geophysik,* in which appears the great annual catalogue of earthquakes.

The solid basis for the modern theory of causation of earthquakes must be credited in largest measure to the Austrian and Japanese schools of seismologists, though many outside these schools have made valuable contributions. Nowhere else in the world has earthquake investigation been carried to the same degree of well-planned refinement as in Japan, and nowhere is there a greater practical need for it. An admirable summary of Japanese achievements along this line is to be found in the recent work issued by the chairman of the famous Earthquake Investigation Committee.[1]

The distribution of seismicity.—The scientific investigations to determine the distribution of seismicity over the *land surface* of the globe may be said to have begun with the compilation of earthquake catalogues. The great catalogue of Perrey,[2] which fills six volumes, was a work which engaged an entire lifetime, and, full of errors as it is, has been the starting-point of all later work. More recently special catalogues have been prepared for particular seismic provinces; such, for example, as those of Milne for Japan,[3] Hoernes for Steiermark,[4] and Baratta for Italy.[5] It has remained for Count de Montessus de Ballore to devote the better part of his lifetime to collecting the scattered material now finally made available and by a process of correlation and standardization to lay the foundations for a new branch of the science—*seismic geography.*

The vast proportions of the work undertaken by the French savant above mentioned[6] will be appreciated when it is stated that the prob-

[1] D. Kikuchi, *Recent Seismological Investigation in Japan,* Pub. E. I. C. (foreign languages), No. 19 (1904), p. 120.

[2] Alexis Perrey, *Les tremblements de terre* (six volumes and a bibliography, Dijon, 1843–71).

[3] J. Milne, "A Catalogue of the Earthquakes Recorded in Japan between 1885 and 1892," *Trans. Seism. Soc. Japan,* Vol. IV (1895), pp. xxi+367, 2 pls.

[4] R. Hoernes, "Erdbeben und Stosslinien Steiermarks," *Mitth. d. Erdbeben-Kom. d. k. Akad. d. Wiss. z. Wien,* N. F., No. 7 (1902), pp. 1–115.

[5] M. Baratta, *I terremoti d'Italia* (Turin, 1901), pp. 960.

[6] F. de Montessus de Ballore, "Relation entre la rélief et la séismicité," *C. R. de l'Acad. des Sc. de Paris,* Vol. CXX (1895), pp. 1183–87.

——— "Introduction à un essai de description séismique du globe et mesure de la séismicité," *Beiträge zur Geophysik,* Vol. IV (1900), pp. 331–82.

——— "Loi générale de la repartition des régions séismiques instables à la sur-

lem which he set himself and carried to a most successful conclusion has been nothing less than the critical examination and cataloguing of all well-authenticated records of earthquakes to determine by a numerical figure the relative seismicity[1] upon a uniform scale of each earthquake province upon the globe; to prepare a composite map of epicenters for each; and, this once accomplished, to examine the topography and geology of each district with relation to its seismicity. No less than 170,000 separate shocks have thus been studied and placed in correspondence with each other.

His catalogue completed, de Montessus' first effort was to determine the relation of areas of high seismicity to the topographic relief. As a result, it is found that the seismic areas are throughout those of steepest general slope:

> In general, one may say that of two contiguous regions—for example, the two sides of a valley, the two flanks of a mountain chain, or plains and neighboring heights—the more unstable is that which presents the greater average slope, or the greater difference in altitude—that is to say, the greater relief either relative or absolute. The reason for this is without doubt that the relief is most frequently in consequence of the importance of dislocations; which, be it because of their lack of equilibrium, or because of the continuation of the tectonic movements which have caused them, quite naturally bring about earthquakes more easily.

The greater number of earthquakes, however, originate beneath the sea, and here, similarly, on the steep margins of the great oceanic deeps. For example, the scarp on the border of the great Tuscarora Deep has been the seat of much the larger number of destructive Japanese earthquakes. The vital question of the relation of earthquakes to volcanic activity, a dependence upon which was a quarter of a century ago the almost universal belief of geologists, is thus answered:

> Finally, while we may cite regions frequently shaken by earthquakes which at the same time have very active volcanoes, one should recognize the fact that

face du globe," *Berichte d. IIten international. Konferenz zu Strassburg, Beiträge zur Geophysik*, Ergänzungsband 2, 1903, pp. 325–34.

——— "Sur l'existence de deux grands cercles d'instabilité séismique maxima," *C. R. de l'Acad. des Sc. de Paris*, Vol. CXXXVI (1903), pp. 1707–9.

——— *Les tremblements de terre: Géographie séismologique;* avec une préface par M. A. de Lapparant; pp. v+475, 99 maps and figures, and 3 plates (Paris, 1906).

A brief account of the work of de Montessus and a list of his papers is given by F. M. Bernard ("Erdbeben Studien des Grafen de Montessus de Ballore," *Die Erdbebenwarte*, 1902, pp. 1–9).

[1] This term here implies both frequency and intensity of seismic shocks.

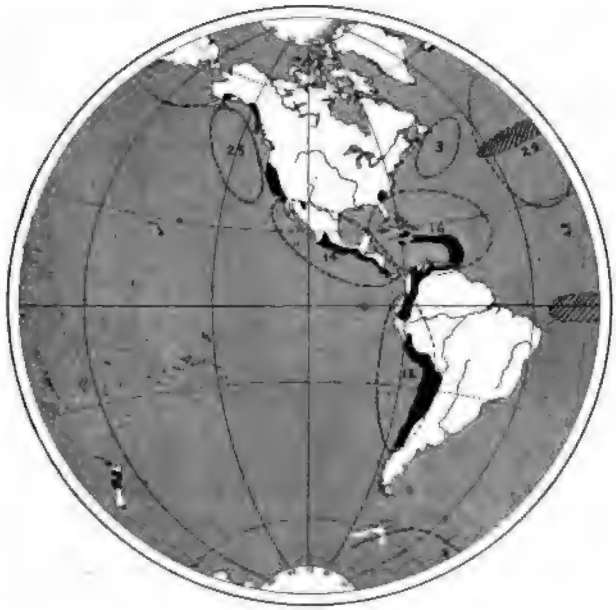

25
3
24
16
14
18

FIG. 1


Continent
Nord Atlantique
Continent
pacifique
hypothetique
Continent
Africano-bresilien

FIG. 2

there is independence of the seismicity and volcanicity . . . . There is coincidence between the unstable regions and eruptions. . . . . But one phenomenon does not in a marked degree cause the other. This last negative law, which clearly results from the statistical researches, requires, however, a more detailed study. From all this we may conclude that, in general, earthquakes are a phenomenon purely geological, and that quite certainly they have their origin in dynamic causes by the effect of which the actual relief of the land is produced and of which they are the ultimate manifestation.

This conclusion of de Montessus is in harmony with that of Milne, who by an analysis of 10,000 earthquake observations in Japan showed that there were comparatively few which had their origin near to the volcanoes of the country.

As regards the broad distribution of the unstable areas upon the globe a most important law is discovered:

The earth's crust quakes in nearly equal amount and in a unique manner along two narrow zones which are disposed on two great circles (in the geometrical sense of the word), *which include between them an angle of about* 67 *degrees—the Mediterranean-Alps-Caucasus-Himalaya circle* (53.54 *per cent. of the shocks*) *and the circumpacific or Andes-Japan-Malay circle* (41.05 *per cent. of the shocks*). *These two zones coincide with the two most important lines of relief of the terrestrial surface.* . . . . . *The zones including the seismic regions coincide exactly with the geosynclinals of the secondary era*, as they have been charted by Haug in his well-known work, *Les géosinclinaux et les aires continentales. The geosynclinals (the most mobile zones of the earth's surface) where the sediments have been deposited in greatest thicknesses, have been energetically folded, dislocated, and re-elevated in the Tertiary period at the time of the formation of the principal actual ranges (or geoanticlinals); and include in themselves, with two or three doubtful exceptions, all the seismic regions* (in the sense which we have given to these two words) *which, in consequence, characterize them.*

Fig. 1, which has been reproduced with additional data from de Montessus' maps, indicates the position of the geosynclinals between the continental areas, and in black the seismic areas. De Montessus' latest work, from which these plates and the above extracts have been taken, has recently issued from the press.[1] This work is devoted to the study of the geological structure of the unstable regions of the globe, and follows as a natural sequel to the completed catalogue of seisms by the same author. The soul of the work, as he frankly admits, is to be found in the generalizations of Bertrand, de Lapparant,

[1] F. de Montessus de Ballore, *Les tremblements de terre: Géographie séismologique;* with a preface by M. A de Lapparant (Paris, 1906).

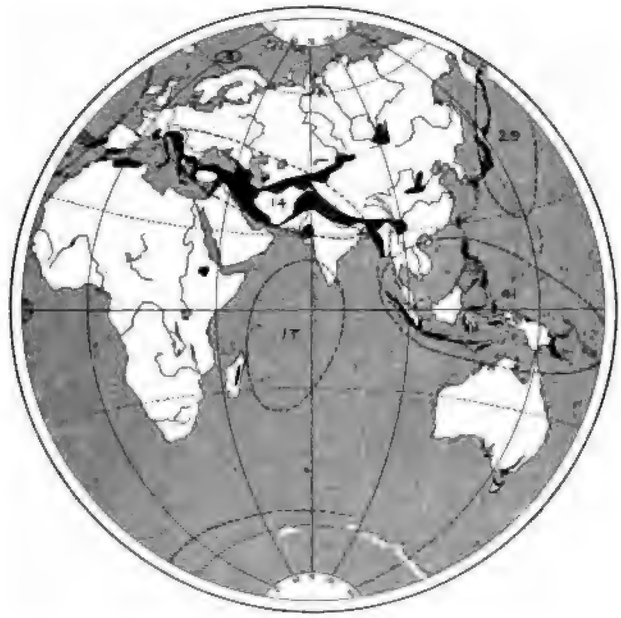


FIG. 3


Continent
Nord - Atlantique
Continent
sino -
siberien
Continent
pacifique
hypothétique
Continent
Africano - brésilien
Continent
Australo - indo - malgache

FIG. 4

de Launay, and Suess; but the book is far more than a perfunctory comparison. It is only necessary to examine with care a few chapters to see that the author has given to each province conscientious study and has brought to his aid the latest researches of individual workers whose papers are not included in the generalizations of his predecessors. It is enough to say that the new volume constitutes a masterly work to which the future generation of geologists will find it necessary often to refer.

The earth's mobile zones.—The generalization of de Montessus, that the areas of high seismicity upon the earth's surface correspond in position to the geosynclinals as mapped by Haug,[1] makes it necessary that the valuable contribution of this savant be examined carefully. Wholly apart from this relationship, however, the paper is of great interest in itself, and should be especially so to Americans.

The conception of a geosynclinal is due to James Hall,[2] though the name was first applied by Dana,[3] who ascribed its folded structure to lateral compression, and not to the weight of the sediments, as did Hall. According to Hall, an enormous accumulation of sediments has followed certain zones of the earth's surface through gradual depression of the sea-floor along these belts; his law being that *the line of greatest depression coincides with the line of greatest accumulation*, a proportion being thus established at each point between the thickness of sediments and the amount of depression. The mountain chains form over the geosynclinals, a classical example being furnished by the Appalachian system. These generalizations Suess has supplemented by showing that within the folded regions the sedimentary series is generally complete and has a certain pelagic character, whereas in the unfolded districts one finds lacunae and intercalations of brackish water deposits.[4]

While Hall insisted that most of the sediments of the geosynclinals had their origin in shallow water, Suess referred to them as having a certain pelagic, and Neumayr even an abyssal, character. Haug's

[1] Emile Haug, "Les géosynclinaux et les aires continentales," *Bull. Soc. géol. France*, 3 Ser., Vol. XXVIII (1900), pp. 617–711.

[2] James Hall, *Nat. Hist. of New York: Paleontology*, Vol. III, p. 70 (Albany, 1859).

[3] J. D. Dana, *Manual of Geology* (2d ed., 1875), p. 748.

[4] Ed. Suess, *Die Entstehung der Alpen* (1875), p. 98.

view is that these sediments were deposited in a depth between that of the shallows and that of the deep sea (more definitely between depths of 80–100 and 900 meters)—a zone to which he has applied the name *bathyal*. Within this zone the geological rock formations are chiefly shales, clays, marls, schists, and compact and nodular limestones; and Haug finds a strong analogy between the distribution of fossils in rocks of this class which were formed during the Secondary era and the distribution of living forms within the bathyal zone of the ocean.

Hall's theory, which regarded the sediments of the geosynclinals as having originated in shallow water, required a most perfect equilibrium to exist between the rate of depression and the rate of accumulation; provided the same lithologic character was to be maintained for great thicknesses; but this adjustment is less necessary if greater depths of the floor of deposition be assumed. Haug expresses the view that in the vast majority of cases a correspondence exists between the axes of folds subsequently developed in a geosynclinal and the axis of the geosynclinal itself, instancing many French examples.

It is, however, the geographical distribution of the geosynclinals and their relation in position to former continents, in which the original contribution of Haug chiefly consists:

> The American authors, to whom is due the notion of geosynclinal, have always taken as the point of departure of their orogenic theories the fundamental idea that mountain chains form on the border of the oceans and that the continents increase by the addition of new chains successively more recent. According to this hypothesis, the geosynclinals should be born at the margin of the continents and the oceans, and should be exclusively of littoral sediments, and the zone of depression where the intensive sedimentation is going on should be separated from the high sea by a mere swell (*bourrelet*). It is easy to demonstrate that it is not under these conditions that the geosynclinals form; and that, far from originating at the margin of the oceans, they are always situated between two continental masses and constitute the mobile zones between masses relatively stable.[1]

As special cases in point the Himalayas and the mountain chains of central Europe are cited, and the general law is thus stated:

> (1) *The geosynclinals, the essentially mobile regions of the earth's crust, are always situated between two continental masses, the regions relatively stable;* (2) *the geosynclinals constituted before their filling marine depressions of a very considerable depth.*[2]

[1] *Loc. cit.*, p. 630. [2] *Ibid.*, p. 632.

After a discussion of the geosynclinals of the different geologic periods, it is added:

Thus follows, even into the details, the conformity of the geologic history of the regions which have been affected by the large foldings of the Tertiary epoch, with those which have been occupied by the geosynclinals during all the Secondary era. If, in certain cases, one finds that the sinuosities described by the geosynclinals have not always been the same during two consecutive epochs, it is none the less true that they are always the same large regions which, since the beginning of Primary time, have been the mobile portions of the earth's crust.[1]

As regards, now the continents which have been separated by the geosynclinals, Haug states:

It results from the summary given that zoögeographic works in all points confirm the conclusions relative to the existence of ancient continents quite different from the actual ones—conclusions obtained before by purely geological considerations. By a series of deductions borrowed from zoögeography we are led to admit the former existence of a *North Atlantic Continent*, of a *Sino-Siberian Continent*, of an *Australo-Indo-Malay Continent*, and of a *Pacific Continent*.[2]

Under the head of the breaking-up (*morcellement*) of the continents, Haug treats of this as having in some cases been accomplished by a gradual transgression of the sea; in other cases, by the production of vertical faults along which blocks of the crust have been depressed to produce abysses (the horsts remaining in relief); and in still other cases, by the depression of a continent in its entirety, so that a basin now occupies its former position, which is bounded by peripheral fractures marked out by volcanoes.

After an extensive study of stratigraphic documents with a view of fixing the positions of areas of transgression and recession of the sea, Haug argues that, if these are to be ascribed to the attraction of the glacial ice or to variations in the velocity of rotation of the planet, there should be alternations of transgression and recession between the polar and the equatorial regions, and also between the two hemispheres. He finds:

(1) *The principal transgressions of the sea are produced simultaneously in the two continents.* (2) *They are produced simultaneously in the polar and equatorial regions.* (3) *They are not universal.*

[1] Ed. Suess, *Die Entstehung der Alpen*, p. 642.

[2] *Ibid.*, pp. 663, 664.

To these generalizations is added the positive one:

Whenever a definite member of the sedimentary series is found in transgression upon the continental areas, the same member will be in recession in the geosynclinals;

and reciprocally:

Whenever a member is found in transgression within the geosynclinals, it will be in recession upon the continental areas.[1]

It should be understood that the views of Haug above expressed set forth the attitude of a particular school of geologists; which views are opposed, as the quotations from Haug indicate, by those geologists who accept the doctrine of continental permanence.

[1] *Ibid.*, p. 682.

Reviews

Die kristallinen Schiefer. By Dr. U. Grubenmann. Vol. I, 1904; Vol. II, 1907. Zurich.

The recent work of Dr. Grubenmann, *Die kristallinen Schiefer*, Vol. I, aims, as its author states in the preface, to explain the characteristics of the crystalline schists, and their occurrence in the crust of the earth, according to chemical-physical laws. Although restricted to one phase of metamorphism, the motive of the work has much in common with *The Principles of Metamorphism* by Dr. C. R. Van Hise. Its general conclusions are, however, quite different.

Dr. Grubenmann briefly follows the historical evolution of conceptions relating to the origin of the crystalline schists, and discusses the original materials of the schists, and their specific characteristics. The cited criteria of sedimentary origin are: stratification, fossil record, micro- and mega-fragmental relicts, conglomerates, ripple-marks, delta formations, gradation phases, chemical composition, and abrupt changes in mineralogical composition within very narrow limits. The criteria given for igneous origin are: chemical composition, gradation phases, and the preservation of original forms of occurrence such as dikes, sills, stocks, and laccoliths.

The processes enumerated by which the original materials are metamorphosed into crystalline schists are mechanical reconstruction, recrystallization, and remineralization. The factors which, in conjunction with time, enter into these processes are solvents, heat, pressure, and the specific characteristics of the original materials.

Dr. Grubenmann makes a threefold division of the crust of the earth into an upper, middle, and lower zone, based on the predominance of one or more of the factors of metamorphism. The belt of weathering (Van Hise) is excluded from the upper zone.

The conditions named for the upper zone are moderate temperature and low hydrostatic pressure, positive heat-toning,[1] and powerful stress. The predominant pressure effect is mechanical. Heat liberation and decrease of volume result from the chemical reactions. The abundance of water favors the development of hydroxide minerals, such as sericite,

[1] The "heat-toning" of a reaction is positive when the sum of the resulting heats of formation exceeds the sum of the heats of formation of the vanished molecule.

chlorite, talc, zoisite, and epidote. These minerals, with quartz and calcite, form the characteristic rocks of this zone—namely, sericite-phyllite, sericite-quartzite, lime-phyllite, albite-phyllite, talc, and chlorite-schists, etc.

The conditions named for the middle zone are higher temperature and intense stress, stronger hydrostatic pressure, and positive and negative heat-toning. The predominant effect of pressure is recrystallization and remineralization with decrease in volume. The minerals assigned to this zone as characteristic are biotite, zoisite, epidote, hornblende, staurolite, garnet, disthene, titanite, magnetite, ilmenite, muscovite, microcline, albite, and oligoclase. The typical rocks of this zone constitute the great mass of the crystalline schists: mica-schists, amphibolites, garnet, and staurolite-schists.

The specified conditions of the lowest zone are enormous hydrostatic pressure and high temperature, very feeble stress, and negative heat-toning. The reactions are inferred to take place with volume increase, since the minerals of this zone nearly all belong to Löwinson-Lessing's "plus" group. ("The molecular volume of the minerals of the plus group exceeds the molecular volumes of the oxides which compose them.") Dr. Grubenmann argues from this that the reactions are probably controlled by temperature and not by pressure. The minerals which are described as peculiar to this zone are cordierite, magnetite, sillimanite, ilmenite, orthoclase, plagioclase, biotite, augite, olivine, and garnet. The gneisses constitute the predominant rocks.

A number of mineral and rock alterations are cited as peculiar to each zone. Olivine of the lowest zone becomes hornblende or garnet in the middle, and serpentine in the upper zone. Granulation of grain, chloritization, and sericitization occur in the upper zone. An aluminous sediment composed of kaolinite, quartz, mica, feldspar, iron oxide, and lime becomes a phyllite in the upper zone, a mica schist in the middle, and a gneiss containing feldspar, sillimanite, and other anhydrous minerals, in the lower zone.

Dr. Grubenmann's threefold division is not intended to apply to all the lithosphere with regard to metamorphic processes, since it is concerned with the development of the crystalline schists only. In a broad way, the three zones collectively correspond to Van Hise's zone of anamorphism and rock-flowage. Anyone who has made a field study of the crystalline schists appreciates the difficulty of classifying them according to the metamorphic processes to which they owe their origin, since no direct observational evidence can be obtained to form the basis of such a classification. Although Dr. Grubenmann refers to the occurrence of schist zones in

certain truncated anticlines, and infers their order of superposition, the reader finds, as a whole, that the field evidence on which his threefold classification is based does not stand out very clearly. In fact, the reader gathers the impression that the threefold classification is based rather on inferences drawn from certain mineral associations than on decisive field observation of the existence of three zones.

Dr. Grubenmann infers that the reactions in the two uppermost zones occur with volume-decrease, since the characteristic minerals of this zone mostly belong to Löwinson-Lessing's "minus" group; i. e., their molecular volume is less than the molecular volume of the oxides which compose them. Most of his readers will probably not agree to this method, but will consider the actual volume-changes involved in the mineral alterations. Various investigators have shown that the alterations described as peculiar to these zones—chlorization, serpentinization, and sericitization—generally involve increase of volume.

In the lower zone also he considers the molecular volume relations between the minerals and their constituent oxides as indicative of the volume-changes caused by the reactions. He argues that the occurrence of "plus" minerals, like orthoclase, plagioclase, and sillimanite, indicates volume-increase. However, calculations of the actual mineral volume-change involved in their formations from other minerals show a decrease in volume.

In the second volume Dr. Grubenmann distinguishes twelve groups on the basis of chemical composition, which are delimited by empirically derived chemical values. The groups take their nomenclature from the rock formations which are peculiar to them. They are: (I) orthoclase gneisses, (II) alumino-silicate gneisses, (III) plagioclase gneisses, (IV) eklogite and amphibolite, (V) magnesian-silicate gneisses, (VI) jadeite rocks, (VII) chloromeianite rocks, (VIII) quartzitic rocks, (IX) lime-silicate rocks, (X) marbles, (XI) iron-oxide rocks, and (XII) alumino-oxide rocks. Each group is subdivided into orders, which are based on the physical characteristics assumed by a group in the upper, middle, and lower zone respectively. A group-name takes the prefix "kata" when it designates a rock of the first order or of the lowest zone. The prefix "meso" is applied to rocks of the middle zone or the second order; and the rocks of the third order or the upper zone take the prefix "epi." Frequently the orders are subdivided into families, based on mineral composition.

The first step in identifying the position of a crystalline schist in Dr. Grubenmann's system is to ascertain its chemical composition. The per-

centage weights of TiO_2 and P_2O_5 are converted into their equivalent weights of SiO_2 and added to the latter. In the same way Fe_2O_3 and MnO are added to FeO, and BaO and SrO are united with CaO. H_2O is neglected. The seven oxides resulting from this elimination are recalculated on a basis of 100, and then converted into molecular percentages. The molecular percentages are then distributed as follows:

S = molecules of SiO_2.
A = sum of molecules of K_2O+Na_2O united with Al_2O_3 in the ratio of 1:1.
C = CaO united to Al_2O_3 in the ratio of 1:1.
F = sum of FeO and MgO. If Al_2O_3 is deficient, the remaining CaO is added to F.
M = CaO added to F.
T = excess of Al_2O_3 after satisfying CaO and the alkalies in the ratio of 1:1.

$$K=\frac{Sio}{6A+2C+F}.$$

These seven so-called group values, S, A, C, F, M, T, and K, are the "empirically derived chemical values" which delimit the groups. Besides these values, Dr. Grubenmann has adapted[1] Osann's[2] projection values, a, c, f, to the chemical classification of the crystalline schists.

The determination of the texture, structure, and mineral content of the schist completes the examination necessary for the complete identification of a schist according to Dr. Grubenmann's system.

Dr. Grubenmann does not claim to have produced a perfect system of classification. The zonal conceptions, he admits, are not entirely free from well-founded objections. A separation into two zones, he believes, would in many cases be more in accord with the facts of occurrence.

Die kristallinen Schiefer may be regarded as an excellent summary of known facts relating to the crystalline schists. It also contains new material. With present incomplete knowledge it is not possible to say whether the proposed classification is warranted and supported by the facts in the field. Perhaps its greatest service to the science consists in proposing a new theory which points out the necessity of a far more detailed investigation of the crystalline schists than has been made thus far.

EDWARD STEIDTMANN

UNIVERSITY OF WISCONSIN

[1] See *Tschermark's minerologische und petrographische Mittheilungen*, Vol. XIX, p. 351.

[2] $a=\frac{20A}{A+C+F}$; $c=\frac{20C}{A+C+F}$; $f=\frac{20F}{A+C+F}$.

The Copper Deposits of the Robinson Mining District, Nevada. By ANDREW C. LAWSON. (University of California Publications, Bulletin of the Department of Geology, Vol. IV, No. 14 [May, 1906] pp. 287–357.)

Many thousands of feet of Cambrian to Carboniferous rocks are exposed in this region. They lie in open folds, and in them are igneous intrusions of post-Carboniferous, probably mid-mesozoic age, and also later intrusions, probably Tertiary. These latest intrusions are of a light-colored, acid, porphyritic rock, and the ore bodies occur usually in them. The ore is low grade, but extensive.

The earlier intrusives are of especial interest in that, while they are post-Carboniferous, the author considers them of the same age as numerous other similar batholiths of the Basin Ranges usually considered archean.

E. W. S.

Water Powers of Northern Wisconsin. By LEONARD S. SMITH. (Water Supply and Irrigation Paper No. 114, U. S. Geological Survey, 1906.) Pp. 145; 5 plates, 5 figures.

Water power is an especially important subject in Wisconsin, because that state is so distant from coal-supply. Mr. Smith points out that the available unused water power is considerable, and makes estimates as to its exact amount. The physical geography and drainage are discussed. A wide highland, 1,000–2,000 feet above the sea, crosses the northern part of the state, from which the drainage goes out in all directions.

E. W. S.

THE JAMES D. DANA MONUMENT, DANA PARK, ALBANY, N. Y.

THE

JOURNAL OF GEOLOGY

MAY-JUNE, 1907

THE METAMORPHIC CYCLE

C. K. LEITH
University of Wisconsin

Katamorphism.—Igneous rocks, when affected by meteoric agencies at and below the weathering surface, tend to become adjusted to their new environment in such a manner that their constituents become distributed as follows:

Original igneous and crystalline rocks	Material removed	Carried as solids	Mechanical sediments— Shales Sandstones Conglomerates, etc.
		Carried in solution	Chemical sediments— Limestone, etc. Cementing materials Vein-filling materials Mineral matter of the sea
	Material remaining............		Weathered rock Residual clays and soils

Fully 97 per cent. of the end-products are sediments included under the general names of shales, sandstones, and limestones. Arkoses, graywackes, conglomerates, etc., containing original complex silicates, may be regarded as intermediate stages of alteration, and may thus be disregarded in a consideration of ultimate products. Of these the shales are by far the dominant sediments, as shown by field observation, by measurement of river loads, and by calculations of the relative proportions of the three sediments necessary most nearly to approximate the composition of the parent rocks. The last method, which is well based, puts the average percentage of shales, derived from the average igneous or crystalline rock, as high as 79 per cent., the sandstones constituting 12 per cent., and the lime-

stones 9 per cent. of the total of these three sediments.[1] Averages of sections made from field observations give uniformly a lower percentage of shales and higher percentage of limestone. An average of twenty-one sections from different parts of the United States shows 30 per cent. of limestone. If the difference of proportion determined by the chemical and field methods is a real one, as inspection of the data used seems to indicate, the significant questions are raised, (1) whether there may not be a concentration of limestones on continental areas, their complementary shales and muds being in the deep sea; or (2) whether limestone may not be concentrated in the upper, observed, part of the lithosphere, because of its known inability to remain in the deep-seated zones of high pressure and temperature. But whether the differences in results reached by the two methods are real or apparent, there is sufficient accordance in the main features of the redistribution of the elements for the purposes of the following discussion.

The changes summarized in the table are destructive or katamorphic (Van Hise) or descensional (Chamberlin and Salisbury). Chemically there is a sundering of complex silicates. The bases, for the most part, go off in solution and are precipitated as oxides, carbonates, sulphides, and even silicates, or remain in solution, a notable instance being sodium chloride. Kaolin develops simultaneously through the hydration in place of the remaining alumina silicates. Neither the free quartz nor other oxides are greatly changed. The mineralogical changes, so far as quantitatively known, may be roughly expressed by a comparison of the minerals of the average parent rock, and of the end-products in above proportion of sediments, as in the following diagram.

Feldspars obviously yield much the largest part of the shales, and a relatively small part comes from the ferromagnesian minerals. Quartz becomes more abundant in the katamorphosed rocks. The quartz of the sandstone may be regarded as corresponding in amount approximately with the free quartz of the igneous rock, indicating that the quartz of the shales is derived largely from the pre-existing feldspars. The minerals of the limestone and allied sediments are

[1] W. J. Mead, "Redistribution of Elements in the Formation of Sedimentary Rocks," *Journal of Geology*, Vol. XV, No. 3, pp. 238 ff.

derived from the bases of the basic feldspars and ferromagnesian minerals.

Physically, katamorphism of igneous rocks to average sediments means a slight increase in average volume of minerals of perhaps 3 per cent., a figure derived by comparing the specific gravities of the

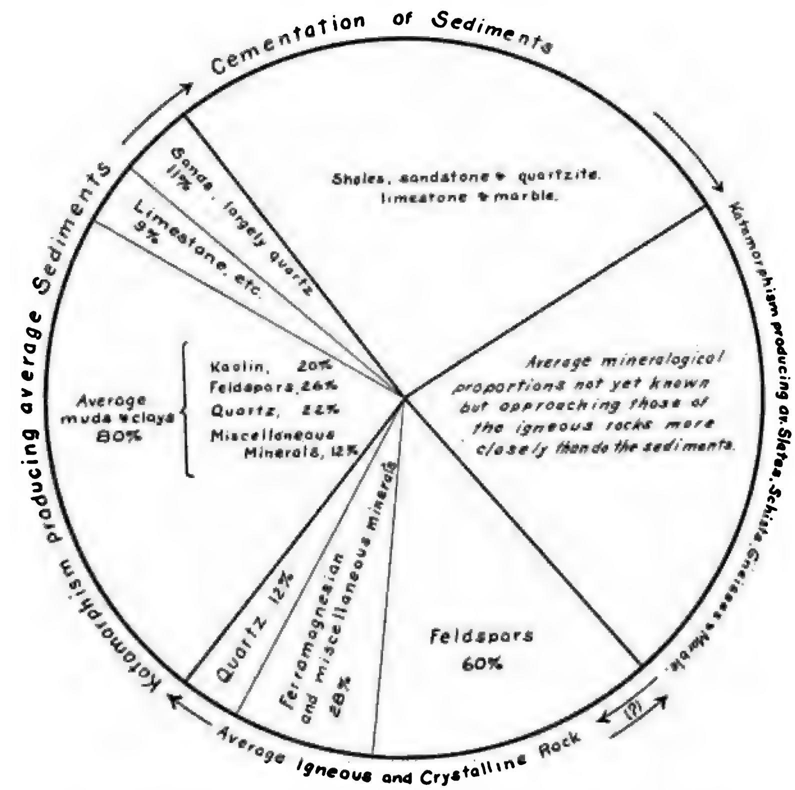


FIG. 1.—Diagram showing mineralogical redistribution in metamorphism.

minerals of the parent rock with those of the resultant average sediments in the stated proportions. A similar result is obtained by calculating volume-changes from the chemical equations of the common alterations of the rock-making minerals to the minerals of the sediments. Where altered to extreme end-products throughout, such as kaolin, quartz, and calcite, there is an average volume-increase of minerals in due proportions, of about 18 per cent. Katamorphism

means a greater volume-increase, by perhaps 40 per cent., when pore-space is figured, on the basis of experimental determinations of pore-space of the different classes of sediments, again combined in the stated proportions. There is still greater increase of volume if the substances remaining in solution, such as salts in the ocean, be calculated as solids. On the other hand, if only the residual materials from weathering are taken into account, not the chemical sediments, it may be shown that in spite of the increase in volume of certain minerals, the mineral volume of each of the principal rocks developed from the residual weathering materials has decreased. Volume-changes will be discussed in more detail in another article.

In general, katamorphism means simplification, both chemical and mineralogical, sorting, segregation of like substances, increase of volume, hydration, carbonation and oxidation—three processes usually involving liberation of heat. There is a net liberation or running-down of energy. Katamorphism is a great concentrating operation, with its maximum effect on igneous rocks, but also acting on sedimentary rocks so far as these contain minerals not already katamorphosed.

Ores, whatever their ultimate origin, while insignificant in bulk as compared with the sediments, illustrate well the net results of repeated concentrations, physical and chemical, under katamorphism. Whether we start with the ores as original magmatic segregations, or with ores resulting from igneous "after-action," or with ores derived directly from the katamorphism of igneous or sedimentary rocks, the ores become concentrated and segregated, and to a certain extent simplified, by katamorphism, and the richness and value of the metallic ore deposits are in a broad way proportional to the extent to which they have been katamorphosed. While some of the magmatic segregations may have value without katamorphism, it is certain that their value is increased by katamorphism. When we consider the iron ores, the lead and zinc ores of the Mississippi Valley, and the oxidized and enriched sulphide zones of copper and other vein and replacement ores, the economic importance of katamorphism in the ore-depositing processes is obvious. A classification of ores in terms of metamorphism is a suitable one for instructional purposes, in that it emphasizes the correlation or identity of ore-depositing and

concentrating agencies with the common ones effecting the metamorphism of the lithosphere as a whole.

Stages in the partial redistribution of the elements above outlined appear in igneous rocks and in sedimentary rocks, so far as these have not become completely adapted to katamorphic conditions. Conglomerates, arkoses, and graywackes are largely in this class. Such partial changes are kaolinization, sericitization, and silicification of acid feldspars, or the alteration of basic feldspars by the development of epidote-zoisite, calcite, or prehnite and kaolin, or the change of augite to hornblende with separation of calcite, or of hornblende to chlorite and epidote with separation of quartz and iron oxide. In fact, most described "metamorphic" changes are of this partial kind, and the fact is frequently lost sight of that the completion of the observed alteration means ultimately the development of the simpler minerals of the sediments. It does not follow that the derivatives of the authigenic minerals of the igneous rocks are in each case less complex chemically than the original mineral. Epidote is as complex as feldspar, hornblende as augite. But the change is accompanied by the separation of other minerals that are less complex, such as kalin and calcite, and there is increase in volume when all end-products are taken into account, making the term "katamorphism" clearly applicable to the alteration. It may be emphasized that the long list of partial alterations of igneous rocks occurring in the upper part of the lithosphere are, with few exceptions, katamorphic in this sense, that they are usually accompanied by a separation of varying amounts of the end-products of alteration observed in sedimentary rocks. This phase of the subject will be discussed in another paper. With this clearly in mind, the study and understanding of the alterations of igneous rocks in upper zones become simplified.

In this connection, the question may be suggested: What are the broad differences between the metamorphism of surface volcanics and plutonic rocks, or between acid and basic rocks? It is not to be supposed that they alter equally in response to the demands of environment. Certain features of these differences are now known, but the subject has not yet been put on a systematic basis.

Cementation.—No sooner do the sediments, the end-products of

katamorphism, reach their maximum incoherency, when the reverse, or reascensional process, is initiated, and they begin to strengthen themselves. Their pore-space becomes lessened under their own weight or that of superior beds, and solutions drop their load in the interstices; the rock becomes cemented. The tendency toward cementation seems by observation to be at its maximum at or just below the level of ground-water. Van Hise defines the belt of cementation as extending from the ground-water level to the lower limit of free movement of water; i. e., to the bottom of the zone of fracture. Cementation consists essentially of a consolidation and selective addition of materials in response to environmental demands for greater coherency. The principal chemical change is due to loss of water and to the proportions of cementing materials added. The resulting rocks are shales, sandstones, quartzites, and limestones, with the same kinds of minerals as in the unconsolidated sediments. The source and nature of the cementing materials may be summarized roughly by comparing the materials available in solution from the weathering of igneous rocks with the requirements of the sediments in the proportions above assumed. Observed percentage losses of elements—alumina being assumed constant, when averaged for cases of so-called "complete" weathering—show frequently about a 33 per cent. total loss of substances in solution when alumina is figured as constant. A hundred pounds of average igneous rocks therefore would contribute to solutions 33 pounds of material, of which 23 pounds is silica, 8 pounds calcium and magnesium carbonates, and the remainder soda, potassa, iron oxides, etc. This material is delivered partly through the overground circulation ultimately to the ocean, and partly to the underground circulation, where it becomes available for cementation. After taking out enough of the materials in solution to afford the ocean salts and the chemical and organic sediments in their known proportion to the total, the overwhelming dominance of silica is apparent in the materials left for cementing purposes. Calculations show that of the net amount of 23 pounds of material available for cementation in our average case, fully 20 pounds are silica. This is not out of accord with observed abundance of cements, when we take into account the mass of silica used in cementing shales, usually not considered. It is possible that,

with liberal allowances for mechanical consolidation, the muds may still use more cementing material than other sediments combined.

Cementation also affects igneous rocks to the extent of filling fissures and other openings, but the process is insignificant in terms of the effect on the igneous rock itself, as compared with the effect on sediments.

Anamorphism.—When the cemented sedimentary rocks reach conditions of sufficient heat and differential pressure—which usually, though not always, means, when they reach the depth of rock-flowage—the reascensional, or constructive, development of the rocks continues under a set of processes which Van Hise has collectively designated as *anamorphic*. The minerals are recrystallized. Some of the simple mineralogical and chemical units become combined into relatively complex ones. The kaolin of shales becomes dehydrated, and this and other alumina silicates present are combined with the minor amounts of bases present to produce anhydrous silicates, which usually develop with a dimensional parallelism to meet the differential stress conditions, giving the rock a flow cleavage or schistosity. The quartz of the sandstones and quartzites combines with the minor amounts of clay and bases present to develop mica or other silicates—again usually, though not always, with parallel structure. The calcite of the limestone recrystallizes coarsely, usually without parallel structure, though sometimes possessing it; and there is a combination of the calcium with the small amounts of alumina silicates and bases which may be present, to develop pyroxenes, amphiboles, garnet, chloritoid, and other heavy anhydrous minerals. Chemically, the dominant processes are silication (and decarbonation) and dehydration, with a little deoxidation. The volume is reduced by closing pore-spaces, by the development of minerals with a higher average density (when taken in proportion of abundance), and, most important, by loss of materials. There is a tendency toward local mixing of substances, rather than segregation. Ores are modified, but not simplified and segregated. Adaptation to environment means, in short, the development of hard, dense crystalline slates, schists, and gneisses, some of the minerals of which approach more nearly in complexity those of the igneous rocks than do the minerals of the sediments.

Whether with more intense anamorphic conditions the sedimentary rocks actually pass into igneous rocks by subcrustal fusion or some analogous process, is yet a question which it is difficult to decide by direct observation, and which is partly a matter of definition. The burden of proof rests on those who hold that actual evidences of the change may be observed. It is easy to conceive that slightly assorted sediments containing essentially the minerals of the original igneous rocks may take on the characteristics of igneous rocks under these conditions; but, in proportion as the ultimate products of katamorphism have been developed and there is corresponding segregation of the simpler compounds, it is difficult to tell how these may again be brought together on any large scale to reproduce the proper mineralogical and chemical combinations of the igneous rocks. While silicates are developed, the main mass retains its simpler chemical characteristics and can be often distinguished from an igneous rock. If, as held by Van Hise, the processes of katamorphism and anamorphism both take place with a liberation or running-down of energy when both chemical and physical factors are considered, the completion of the metamorphic cycle on any broad scale seems doubtful.

It is further not clear whether the development of schists and gneisses from igneous rocks is predominantly katamorphic or anamorphic for the minerals of the igneous rock. In some observed cases the change is clearly katamorphic, such as the common development of hornblende from augite, of the alteration of a basic feldspar to a more acid feldspar with separation of clay and calcite, or the alteration of a potash feldspar to kaolin and sericite, although, as already indicated, one of the resulting minerals may be fully as complex as the original minerals. It is also equally certain that the observed development of heavy, anhydrous minerals, such as garnet, in the schistose igneous rocks means anamorphism.

The cycle.—The sequence of destructive and reconstructive changes above outlined constitutes a partial metamorphic cycle. If the slates, schists, or gneisses ever take on the characteristics of igneous rocks, through fusion and mixing, the cycle is complete. A necessary consequence of the cycle theory is that in the same zone changes may be both destructive and constructive—destructive to

igneous and crystalline rocks, constructive to sedimentary rocks made up of end-products of katamorphism. It is true that the katamorphism of an igneous rock is most rapid and effective at the surface, while the cementation of the sediments occurs best at and immediately below ground-water level, and anamorphism of sediments begins only when the zone of rock-flowage has been reached. Thus there is a vertical succession of metamorphic zones, each with its own distinguishing characteristics; but in each of these are

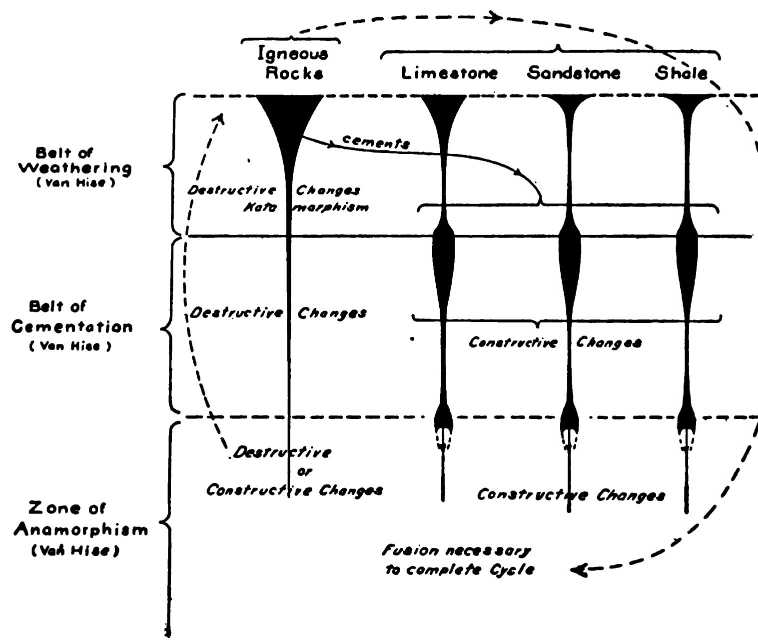


FIG. 2.—Sketch to show principal changes of principal rock in relation to zones of metamorphism. Thickened line indicates locus of maximum change. Horizontal lines indicating boundaries of zones are not corrected for thickness of zones or varying depth of zones for different rocks.

subordinate changes on opposite sides of the cycle. Katamorphism of an igneous rock near the surface is important, while, in the same zone, there is a minor amount of cementation of sedimentary rock. Cementation of sedimentary rock is important below ground-water level, where an igneous rock undergoes a relatively small amount of katamorphism. Anamorphism of certain sediments, especially

shales, may occur, while igneous rocks under the same conditions tend to katamorphism. In a highly idealized form the distribution of the changes with regard to zones, kinds of rocks, and kinds of changes, may be represented as in the figure on p. 312, in which the extent or importance of the change is represented in each case by thickness of line.

Van Hise states that the processes in each of the metamorphic zones may be reversed, thus in a way recognizing the cycle principle, but his full discussion emphasizes the dominant conditions and changes of the zones to such an extent that the student sometimes infers that all rocks in a given zone act alike. Grubenmann described three zones of schist-making—upper, middle, and lower—with the implication that all rocks suffer uniform changes in a given zone. Chamberlin and Salisbury imply the cycle idea in their use of the terms "descensional" and "reascensional" as applied to rock-changes, though the account of alterations and conditions is necessarily elementary. It is the purpose of the present paper to emphasize the necessity of the cycle theory in interpreting the zones of metamorphism. The "zonal" classification permits of necessary grouping of dominant phenomena, but confusion is likely to result unless the zones are considered in connection with particular rocks and alterations, and contrasting kinds of results for each zone are clearly discriminated.

Rôle of igneous rocks in metamorphic cycle.—The part taken in the metamorphic cycle by contact action of igneous rocks is most conspicuous in the anamorphic or constructive phases of the cycle, and may be regarded in general as furnishing higher temperature and pressure and hot solutions for the acceleration of anamorphism and for developing anamorphism in higher zones where the conditions are otherwise not anamorphic. Along the contacts are developed dense, complex, anhydrous silicates, such as garnet, staurolite, andalusite, amphibole, pyroxene, etc., and the rocks are recrystallized. Yet it is also true, especially near the surface, that the advent of igneous rocks brings about katamorphism in the adjacent rocks through the agencies of the hot waters and gases, magmatic, meteoric, or both, accompanying and following their introduction. In this class probably belong in part the prophylitic and allied alterations adjacent to

ore-bearing veins in igneous rocks. The quantitative classification of igneous contact effects in terms of katamorphism and anamorphism has not yet been accomplished, or for that matter more than begun on any systematic scale. It is likely to yield interesting results. But whatever the specific relations of the influences of igneous rocks with conditions determined by depth they should require little essential revision of our conception of the metamorphic cycle for the reason that the cycle is based on a comparison of net results, and not on a comparison or weighting of the specific causes which have contributed to these results.

Classification of rocks.—The term "metamorphism" has in the past been largely applied to the development of slates, schists, and gneisses. This use of the term is implied in the prevalent textbook classification of rocks into igneous, sedimentary, and metamorphic divisions. The student comes to realize only with difficulty the fact that sedimentary rocks result from alteration of igneous rocks, just as do the so-called metamorphic rocks. Van Hise and others have included all rock alterations under metamorphism, and the same practice is observable in the descriptions of rock alterations by certain petrographers when they include under metamorphism many mineral changes which ultimately develop the sedimentary minerals. The development of the cycle idea further emphasizes the necessity of the broad use of the term "metamorphism," and the desirability of Van Hise's terms, "anamorphism" and "rock-flowage," to cover the schist-making changes formerly alone considered under metamorphism. With terms thus defined, the primary genetic classification of rocks becomes a dual one, ***igneous*** and ***metamorphic***, the latter class being dually subdivided into the contrasting ***sedimentary*** and ***schist-slate-gneiss*** groups.

NOTES ON THE PALEOZOIC FAUNAS AND STRATIGRAPHY OF SOUTHEASTERN ALASKA[1]

E. M. KINDLE
United States Geological Survey, Washington, D. C.

INTRODUCTION

The localities referred to in this paper are located on the islands of the Alexander Archipelago and along the shores of the narrow coastwise strip west of British Columbia sometimes called the Panhandle of Alaska.

During the summer of 1905 the writer, in company with Mr. C. W. Wright, made a boat journey of about 600 miles along the coasts to the southeast of Glacier Bay and the Lynn Canal. Collections were made from nearly all of the localities at which fossils had previously been found in this region by Mr. Wright and others, and from a number of new ones.

The trip was undertaken primarily for the purpose of aiding in the work of correlating and mapping the rocks of southeastern Alaska, upon which Messrs. F. E. and C. W. Wright have for some time been engaged. Alaskan faunas have a wide general interest to paleontologists, owing to their intermediate position between the faunal provinces of America and Asia. So little has been published on the faunas of this important region that a preliminary statement of the results thus far obtained seems justified in advance of the comprehensive work of the Wrights. A brief statement of the stratigraphic succession is essential to the comprehension of the summary of the faunas. In presenting this outline of the stratigraphic succession the writer wishes to acknowledge his indebtedness to previous workers in this region, and particularly to the Wrights, upon whose work it is in part based. More explicit reference to the previous work in the region is offered in the following brief discussion of the more important contributions relating to this field.

[1] Published by permission of the Director of the U. S. Geological Survey.

LITERATURE

Casual observations on the Paleozoic rocks of southeastern Alaska appear in the writings of some of the travelers who visited the region during Russian occupation. The most important of the early papers is one by Dr. Grewink, a Russian, who, although he never visited Alaska, published a paper in 1850[1] which contains many geographical and some geological data concerning southeastern Alaska. This work is based largely on collections and data obtained by a Russian naval officer. The finding of a loose specimen of the Silurian fossil *Catenipora escharoides* near Sitka is reported by Grewink.[2]

In 1855 Isbister published a summary of then existing knowledge of the geology of northwestern America, with a geological map which included Russian America.[3] The data relating to southeastern Alaska[4] are drawn from Grewink and the "Geological Appendix" to Captain Beecher's *Voyage to Behring Straits*. The crude inaccuracy of the map made it of little or no value as a basis for actual work in the region.

In 1863 Mr. W. P. Blake made a reconnaissance of the Stikine River and published some notes on the rocks observed.[5] In 1868 Mr. T. A. Blake published a paper[6] on southeastern Alaska which contains observations on the lithologic characters of the rocks near Sitka and along Chatham Strait.

The pioneer work of George W. Dawson on the Chilkoot Pass and Stikine River[7] sections in 1888, and of C. W. Hayes along the Taku Inlet and River in 1891,[8] was the first important contribution

[1] "Beitrag zur Kenntniss der orographischen und geognostischen Beschaffenheit der Nord-West-Küste Amerikas mit den anliegenden Inseln," *Verhandlungen der Russischen kaiserlichen mineralogischen Gesellschaft zu St. Petersburg*, 1848, 1849 (1850), pp. 76—432.

[2] *Ibid.*, p. 93.

[3] *Quarterly Journal of the Geological Society of London*, Vol. XI (1855), pp. 497–520, map.

[4] *Ibid.*, pp. 518, 519.

[5] *Petermans Mitteilungen*, Vol. X (1864), pp. 171–75. 4°.

[6] *American Journal of Science*, Second Series, Vol. XLV (1868), pp. 242–47.

[7] *Annual Report of the Geological Survey of Canada*, N. S., Vol. III, Part 1, pp. 53*b*–59*b*, 176*b*.

[8] *National Geographical Magazine*, Vol. IV (1892), pp. 117–59.

to our knowledge of the stratigraphy of southeastern Alaska. These three traversers of the coastwise belt established the fact that the sedimentaries are cut by a granite belt of great width and length.

In 1892 Mr. H. P. Cushing, a member of Professor Reed's party, published a paper on the bed-rock geology about Glacier Bay, which includes a report on a small collection of fossils from a limestone having "a thickness of several thousand feet." These were determined by Professor H. S. Williams as Paleozoic.[1] Later this collection, with the addition of a coral which appears to have been obtained from a glacial moraine, was reported to be Carboniferous on the authority of Professor Williams.[2] Professor J. J. Stevenson, who obtained the coral considered it and the Leperditias to indicate a horizon "not younger than Middle Devonian."[3]

Professor H. F. Reid in 1895 published a report on "Glacier Bay and Its Glaciers,"[4] in which he quotes this determination by Williams of the Carboniferous age of the Glacier Bay limestones. On the basis of this determination Reid suggests the correlation of the Glacier Bay "Carboniferous" and some of the argillites and limestones described by Hayes in the Taku section, 100 miles to the eastward, with the Glacier Bay limestones. The Cambro-Silurian age of the argillites underlying the limestone at Glacier Bay is suggested by Reid because of a supposed analogy of his section to one of Dawson's some 300 miles to the southeast, in which Carboniferous faunas are said to follow a Cambro-Silurian horizon. The Cushman fossils were later examined by Schuchert, who reported them to be Silurian, with the exception of the coral from the moraine, concerning which Schuchert agreed with Stevenson in reporting it to be an *Acervularia*, representing a Devonian horizon.[5] Fossils recently collected by the Wrights leave no question as to the Silurian age of the Glacier Bay limestones.

In 1895 Messrs. Dall and Becker visited southeastern Alaska in order to study its gold and coal resources. The observations on the

[1] *National Geographical Magazine*, Vol. IV (1892), p. 59.

[2] *Sixteenth Annual Report*, U. S. Geological Survey, Part 1, p. 434.

[3] *Scottish Geographical Magazine*, Vol. IX (1893), p. 70 (separate p. 5).

[4] *Sixteenth Annual Report*, U. S. Geological Survey, Part 1, pp. 433, 434.

[5] Brooks, *Professional Papers No. 1*, U. S. Geological Survey, p. 20.

stratigraphy in Mr. Becker's paper[1] relate to the rocks in the vicinity of the gold mines. No correlations with rocks elsewhere are attempted.

Dall's paper, which relates solely to post-Paleozoic rocks, has attached as an appendix a paper by Charles Schuchert.[2] This paper gives a list, with notes, of fossils obtained at Kuiu Island by Messrs. Dall, Becker, and Brightman. Professor Schuchert referred these fossils to two horizons, the Devonian and Carboniferous. It will be shown elsewhere in this paper that all of these fossils are of Upper Carboniferous age.

In 1901, Mr. Alfred H. Brooks,[3] incidental to a study of the mineral deposits of the Ketchikan district, collected considerable data on areal and structural geology. He also carried a hasty reconnaissance northward as far as Skagway, and thence westward to Sitka. In his report he brought together, not only his own data, but also those of previous investigators, and included a geologic sketch map of southeastern Alaska and a provisional table of correlations.

Mr. Arthur C. Spencer[4] in 1903 made a study of the geology and mineral resources of a strip of the mainland extending southward from Berners Bay to Snettisham, while in the same year Mr. C. W. Wright[5] carried a reconnaissance northward to the international boundary in the Porcupine district, in which he has shown the presence of a Carboniferous limestone. Since then Messrs. F. E. and C. W. Wright have extended their work so as to cover nearly the entire province, but only their preliminary statements have been issued. Accompanying one of these is a preliminary geological map[6] covering most of the area.

Professor B. K. Emerson, one of the geologists of the Harriman expedition, has published some notes on the lithology and correlation of the rocks at points where their steamer touched.[7] Most of these

[1] *Eighteenth Annual Report*, U. S. Geological Survey, Part 3 (1898), pp. 7–86, 96, 97.

[2] "Report on Paleozoic Fossils from Alaska," *Seventeenth Annual Report*, U. S. Geological Survey, Part II, pp. 898–906.

[3] *Professional Paper No. 1*, U. S. Geological Survey, pp. 1–119; *Bulletin of the Geological Society of America*, Vol. XIII (1901 [1902]), pp. 253–66.

[4] *Bulletin No. 287*, U. S. Geological Survey, 1904 (1907).

[5] *Bulletin No. 236*, U. S. Geological Survey, 1904.

[6] *Bulletin No. 284*, U. S. Geological Survey, 1906, pp. 30–54, Plate 11.

[7] *Ibid.*, p. 20.

relate to Mesozoic terranes. In his observations on Glacier Bay Professor Emerson revives an old error by referring the limestones of that locality to the Carboniferous,[1] unaware, apparently, that they had been shown to be of Silurian age.[2]

Quite recently Brooks has briefly summarized the more essential facts concerning the stratigraphic succession in southeastern Alaska.[3] A small-scale geologic map of the whole of Alaska, so far as covered by surveys, accompanies this report. In this paper appears the first notice of the presence of Silurian horizons at Freshwater Bay and Kuiu Island.

GENERAL GEOLOGIC RELATIONS

Southeastern Alaska is a region in which a wide range of geologic agencies have operated to produce a complex and intricate stratigraphic record. Volcanic and igneous rocks, either as surface flows or as intrusions, have been developed in this area at frequent intervals

[1] *Harriman Alaska Expedition*, Vol. IV (1904), pp. 16–23.

[2] A. H. Brooks, *Professional Paper No. 1*, U. S. Geological Survey, 1902, pp. 19–21.

[3] "The Geography and Geology of Alaska," *Professional Paper No. 45*, U. S. Geological Survey, 1906, pp. 208, 210, 211, 219, 221, 222.

from the Paleozoic down to the present. The sedimentary beds are known to include Tertiary, Mesozoic, and Paleozoic horizons as far back as the Silurian. By far the greater part of the sedimentaries belong to the Paleozoic, but a considerable thickness of the Mesozoic has been found in a few sections. The Mesozoic and Paleozoic beds have been folded together in a series of flexures, generally of the open fold type after which the Tertiary, now found only in a few isolated basins, was deposited upon them. The general direction of the strike of the beds is northwesterly and southeasterly, approximately parallel to the coast-line. The inclined beds have been cut by extensive intrusions. These take courses parallel in a general way to the strike of the sedimentaries. The granites, which comprise the bulk of the Coast Range mountains, are the most important of these intrusive masses. This granite belt has a width of 40 to 80 miles, and extends the entire length of the coast strip and beyond it both north and south. Granite intrusions, which are usually more or less local in character, occur through the islands. The older rocks over considerable areas in some parts of the region are buried under lavas of Tertiary age.

The shales and limestone of the sedimentary series have in many parts of the region been altered to marbles and schistose rocks by the intrusives and deformational agencies. Frequently the alteration has been sufficient to destroy all traces of organic remains.

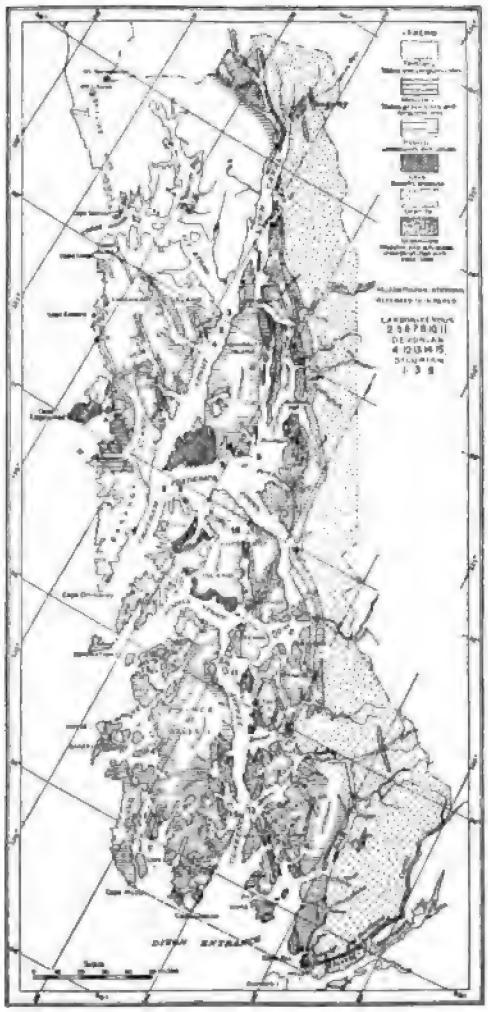
The general order of the stratigraphic succession is shown in the following table:

PROVISIONAL TABULAR STATEMENT OF STRATIGRAPHY

Age		Lithological Character	Correlation with Nomenclature of Brooks*	Thickness Feet
Carboniferous	Upper Carboniferous	Light-colored limestone	Ketchikan series	600±
	Middle Carboniferous	Argillites, cherts, shales, sandstone, and greenstone		?
	Lower Carboniferous	Dark-gray limestones and interbedded cherts		1500±
Devonian	Upper Devonian	Dark-red volcanic material, limestone and greenstone		?
	Middle Devonian	Gray limestone	Vallenar series	200±
	Lower Devonian	Gray limestone		200±
Silurian		Gray and buff limestones	Wales series	3000±
Silurian or pre-Silurian		Graywacke, cherts, and some dark limestone		?

* *Professional Paper No. 1*, U. S. Geological Survey, 1902, pp. 41–45.

The limits of the three subdivisions or series of the Paleozoic proposed by Brooks, which are shown in the preceding table, correspond to those of the Carboniferous, Devonian, and Silurian rocks of the region, so far as they were recognized at that time.



Our present knowledge of the section is too incomplete to make any definite statements concerning the contact relations of the several divisions of the column. While it is probable that unconformities exist within the Paleozoic, evidence of them has not been observed by the writer.

Brooks observed what he considered evidence of unconformity at the base of the Devonian at Long Island (13)[1] and Vallenar Bay (12).[1] It may be stated, however, that at neither of these localities is the age of the "older beds" known. The evidence of unconformity consequently rests on the character of the contact between the Devonian and the older beds. This relationship, as observed by the writer at Long Island, appears to be open to another possible interpretation than that of unconformity. On the north side of Long Island the

[1] Numbers refer to collecting stations on map. *Professional Paper No. 1*, U. S. Geological Survey, 1902, p. 21.

relative position of the limestone and inferior beds may be the result of a fault which has lifted the basal igneous beds considerably higher than the limestone at one or more points. On the south shore the strike and dip of the limestones and the underlying igneous beds, which probably represent submarine volcanic flows, were in harmony where observed. In referring to this supposed unconformity the writer wishes not to deny its existence, but to point out that further evidence is required to demonstrate it.

The preliminary geological map by Messrs. F. E. and C. W. Wright is here reproduced[1] in order to show the location of the points from which the fossils on which this paper is based were obtained. The several collecting stations are indicated by numbers, and the horizon of each is shown by a geological grouping of the numbers at the margin of the map.

SILURIAN

The oldest fauna which has been found in the region is of Silurian age. A great thickness of rocks, mostly argillites, underlies the limestones holding Silurian fossils. These lower beds, in which no fossils have been found, have an aggregate thickness of several thousand feet, as exposed on the west coast of Kuiu Island. The great thickness of these beds and their position below limestones known to be of Silurian age strongly suggest their pre-Silurian age, although no paleontologic evidence of this has been obtained.

Two horizons of the Silurian have been recognized. The older of these is represented by a small fauna which has been found on the northwest coast of Kuiu Island (10).[2] In the limestones northeast of Mead Point the following fauna occurs:

Diphyphyllum ? sp.	Holopea cf. servus Barr.
Conchidium knighti (Sow.)	Murchisonia sp.
Whitfieldella sp.	

None of the species are abundant, with the exception of *C. knighti*, which is represented by great numbers of large shells in one thin bed of limestone.

C. knighti is one of the characteristic fossils of the Aymestry limestone of the Ludlow group of England. It is known also from

[1] Republished from *Bulletin No. 284*, U. S. Geological Survey, 1906.

[2] Locality numbers refer to the map.

Russia and Bohemia. There appear to be no authentic records of its occurrence in the Silurian faunas of the United States. The nearest equivalent of this fauna in eastern America is the Niagara fauna. While none of the species collected are identical with Niagara species, *Conchidium knighti* is very closely related to *C. nysius* of the Niagaran fauna.

The Kuiu island fauna occurs in the midst of a limestone series which appears to be 2,000 feet or more in thickness. Other portions of the series which were examined appeared to be barren. Upward

FIG. 1.—Silurian beds at Freshwater Bay.

these limestones seem to terminate with volcanic breccias, while below they pass into cherts and argillites of undetermined age.

The later Silurian horizon does not appear to be present in the Kuiu Island section. It occurs at Freshwater Bay (4), where more than a thousand feet of gray limestones, which precede the beds carrying Devonian fossils, outcrop along the south side of Freshwater Bay. The appearance of the lower portion of this series is shown in the accompanying photograph (Fig. 1). The lower two-thirds of this series comprises dark-gray, thinly laminated limestones. *Leperditias* of an undetermined species occur abundantly in certain beds in the lower part of the series. A few fragments of another and larger crustacean, probably a *Ceratiacaris*, are associated with them.

These crustaceans comprise the fauna of the lower 700 feet of the section, so far as discovered.

In the upper 300 feet of the limestones of the section a crustacean fauna also predominates, but the types represented are unlike those of the preceding division. One of the conspicuous forms in this fauna is a large undescribed ostracod provisionally referred to *Isochilina* by E. O. Ulrich, having a length of 1¼ inches. Fragmentary specimens indicate the presence of one or more other species of large ostracods, which together with a new species of *Ceratiacaris* are associated with the large *Isochilina*. Other forms occurring in this portion of the section are *Zaphrentis?* sp., represented by a single specimen, *Meristella tumida* Dalm.? and *Megalomus* sp. undt. The *Megalomus* is a large and very thick-shelled bivalve comparable in this respect with *Megalomus canadensis* of the Guelph, and identical with a species occurring in the limestone at Glacier Bay.

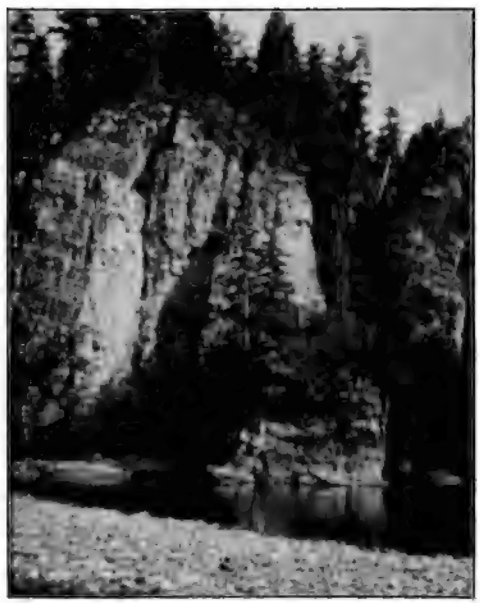


FIG. 2.—Upper Carboniferous limestone, Hamilton Bay, Kupreanof Island.

While none of the forms occurring in the two lowest divisions of this section have been identified with known species, the dominance of the large ostracods and the massive-shelled *Megalomus* and thick-shelled *Murchisonias* point to a late Silurian age of the fauna. The horizon represented is apparently about that of the Guelph.

The Silurian fauna of Freshwater Bay is found also at Glacier Bay, to the northwest. A small collection in the National Museum made by Cushman, and a much larger collection by Mr. F. E. Wright,

show the faunas of the two localities to bear the closest resemblance.

The horizon represented by the fauna at Freshwater and Glacier Bays is not known as yet elsewhere in Alaska. The Kuiu Island Silurian fauna differs very materially in its facies from other known Silurian faunas of Alaska, but the same horizon appears to be represented by the Silurian found by the writer on the Porcupine River, in northeastern Alaska, during the last summer.

FIG. 3.—Lower Devonian limestone (*B*) and basal igneous beds (*A*) at Long Island.

DEVONIAN

No complete section of the Devonian is known in southeastern Alaska. The collections from various points taken together, however, show the presence of Upper, Middle, and Lower Devonian horizons. The earliest fauna of the Devonian which has been found occurs in the section at Long Island, Kasaan Bay (13). The bedrock of the shores of the bay is composed chiefly of the Kasaan greenstones and cherts. The limestone of Long Island and its associated igneous rock is supposed to be interpolated in the greenstone series. The surface rocks of the island comprise a limestone series resting on

a bedded igneous rock, with which the limestones appear to be conformable. Both series are shown in Fig. 3. An estimate of the thickness of the beds along the south shore of the island gives the following section exposed between the east end of the island and the inlet to the Salt Pond:

	Feet
c. Hard, dark-gray limestone, slightly darker than *b*	270
b. Hard, blue, fine-grained limestone, fracturing easily in any direction .	200
a. Stratified buff or cream-colored siliceous beds of igneous origin . . .	90
	560

FIG. 4.—Middle Devonian limestone, Long Island.

The two divisions of the limestone series are conformable with each other, and the upper and lower portions are very similar in lithologic characters. Fig. 4 shows the lower beds of division *c*. The faunas of the two divisions of the limestone, however, show marked differences. The fauna of the upper portion of the limestone series was first discovered by Brooks, who collected some fossils from it which Schuchert determined as Middle Devonian.[1] The lower fauna appears not to have been represented in the collection studied by Schuchert. The character of the fauna in the lower portion of the limestone series is indicated by the following list:

[1] *Professional Paper No. 1*, U. S. Geological Survey, p. 43.

Stictopora sp.
Cladopora sp.
Delthyris sulcatus Hisinger.
Sanguinolites sp.
Cardiola sp.
Hercynella nobilis Barr.
Hercynella bohemica Barr.
Holopea sp.
Murchisonia angulata Phillips.
Murchisonia sp. 1
Murchisonia sp. 2
Planitrochus sp.
Planitrochus near amicus (Barr.) Perner.
Loxonema sp.
Holopella sp.
Trochonema sp.
Euomphalopteris ? sp.
Beyrichia ? sp.
Leperditia sp.
Orthoceras sp.
Orthoceras near anguliferas de Arch. and de Vern.

The occurrence of the genus *Hercynella* in this fauna is of considerable interest, since it has not been found heretofore in America. *H. bohemica* occurs in the lower Devonian of the Ural Mountains. Both *H. bohemica* and *H. nobilis* are present in Étage F of Barrande's Bohemian section. Their presence in the fauna at Long Island indicates that the latter is much more closely related to the European and Asiatic than to the American faunas outside of Alaska. This lower fauna at Long Island represents the lowest Devonian horizon which has been found in southeastern Alaska.

In the upper portion of the higher limestone, *c*, the following fauna is found:

Favosites radiciformis Rom.
Cyathophyllum sp.
Orthophyllum ? sp.
Zaphrentis sp.
Calceola cf. sandalina Lam.
Syringopora sp.
Lingula sp.
Atrypa spinosa Hall.
Atrypa reticularis (Linn.)
Atrypa hystrix Hall.
Gypidula optatus (Barr.)
Gypidula cf. intervenicus (Barr.)
Meristella cf. barrisi Barr.
Stropheodonta stephani (Barr.)
Stropheodonta comitans Barr.
Spirifer sp.
Spirifer hians Bich. ?
Spirifer thetidis Barr.
Spirifer subcomprimatus Tsch.
Spirifer sp.
Spirifer indeferens Barr.
Spirifer sp.
Reticularia ? sp.
Rhynchonella cf. amalthea Barr.
Rhynchonella livonica Buch.
Pugnax sp.
Dalmanella occlusa Barr.
Schizophora macfarlani Meek. ?
Schizophora striatula Schloth.
Streptorhynchus sp.
Camarotochia ? sp.
Cypricardinia ? sp.
Conocardium cf. bohemicum Barr.
Conocardium sp.
Lucinia cf. proavia Goldf.
Leptodesma sp.
Mytilarca ? sp.
Nuculites sp.

Telinopsis sp.
Holopella ? sp.
Loxonema ? sp.
Murchisonia sp. 2.
Murchisonia sp. 1.
Naticopsis sp.
Oriostoma sp.
Oriostoma princeps var. Oehlert.
Euomphalus cf. planorbis d'Arch. and Vern.
Tremanotus cf. fortis Barr.
Tentaculites sp.
Ooceras sp.
Gomphoceras ? sp.
Orthoceras sp.
Cytherella ? sp.
Entomis pelagica Barr.
Lepterditia sp.
Cyphaspis sp.
Proetus sp.
Proetus cf. romanooski Tsch.

In place of the gasteropods, which are the dominant forms in the lower horizon, brachiopods are the predominant group in this upper fauna. The *Hercynellas,* which are abundant at one horizon in the lower beds, appear to be entirely absent. The upper fauna, however, agrees with the lower in its foreign affiliations. In it occur the peculiar coral *Calcoela,* common in the Middle Devonian of Europe, but not recorded from the American Devonian. Several species among the brachiopods are either identical with, or have their nearest analogues in European species.

The lower 40 feet of division *c* of the Long Island section furnished a fauna differing but slightly from that of the upper part. The following list indicates its character:

Cladopora ?
Cyathophyllum sp.
Camarotoechia sp.
Meristella cf. ceras Barr.
Spirifer sp.
Spirifer cf. thetides Barr.
Spirifer cf. cheiropteryx
Stropheodonta comitans Barr.
Orthonota sp.
Schizodus sp.
Conocardium cf. bohemicum Barr.
Euomphalus planorbis d'Arch and Vern.
Oriostome princeps var. Oehlert.
Tentaculites
Cyrtoceras sp.
Orthoceras sp.
Proetus cf. romanooski Tsch.

Both faunules of this upper limestone (*c*) are regarded as representing a Middle Devonian horizon.

There are no Devonian faunas in the United States with which the Long Island faunas can be compared. Their affinities seem to be all with the European faunas.

The Middle Devonian is represented also by a fauna occurring at Freshwater Bay (4), in the northeastern part of Chichagof Island.

On the south side of the bay the Silurian series previously described in this paper is terminated by 50 feet or more of Devonian limestones. These are dark steel-gray in color, somewhat arenaceous, and lie in strata 1 to 4 feet thick. These higher beds, which are largely covered at high tide, furnished the following species:

Orbiculoidea sp.	Goniophora sp.
Chonetes cf. verneuile Barr.	Pterinea sp.
Camarotoechia cf. billingsi Hall.	Pterinopecten sp.
Leptostrophia n. sp.	Schizodus sp.
Stropheodonta sp.	Goniatites sp.
Stropheodonta stephani Barr.	Orthoceras sp. 1.
Stropheodonta cf. fugax (Barr).	Orthoceras sp. 2
Pentamarella ? sp.	Bellerophon sp.
Reticularia ? sp.	Naticopsis sp.
Schizophoria sp.	Oriostoma sp.
Atrypa reticularis	Leperditia sp.
Cypricardinia ? sp.	Dalmanites sp.
Cypricardinia contexta Barr.	Proetus romanooski (Tsch.)

This fauna has but little resemblance to any of the Devonian faunas of eastern America. Its nearest faunal equivalents are to be found in the Devonian of central Europe and Russia. Two of the species occur in Étage F of Barrande's Bohemian section. One of the trilobites which occur abundantly in this fauna appears to be identical with species described by Tschernyschew from the Ural Mountains as *Dechenella romanooski*. The presence of such forms as *Goniophora* sp., *Goniatites* sp., and *Proetus romanooski*, together with the general aspect of the fauna, points very clearly to its Middle Devonian age.

In the Freshwater Bay section igneous beds appear to occupy the entire upper Devonian interval. At Klawack (14), on the west coast of Prince of Wales Island, however, Mr. C. W. Wright made a small collection of fossils which show the presence of an Upper Devonian fauna in the southern part of the southeast Alaskan district. It contains *Zaphrentis* sp., *Productella hallana* Walcott, and *Spirifer anossofi* Vern. The two latter are represented by a number of specimens, and seem to be the most abundant fossils at the locality. *Sp. anossofi* is representative of the Ural Mountains fauna, but is closely related to *Spirifer hungerfordi* of the Iowa Devonian. *P. hallana*

is a common species in the western American Devonian, and is also found in the Ural Mountains. At another locality C. W. Wright has found *Spirifer disjunctus*. The discovery of these fossils distinctly proves the presence of the Upper Devonian fauna in southeastern Alaska. In many of the sections, however, the fauna will probably be found to be absent, owing to the prevalence of submarine volcanic flows during the Upper Devonian interval.

The Devonian section of southeastern Alaska resembles that of the Upper Yukon in respect to the important rôle played by igneous rocks in each. So far as the two sections are known, however, the sedimentary members present no strong points of similarity, except that the lowest member of each is a limestone formation. The faunas of the two regions are entirely unlike each other. The Mackenzie River section, which is the nearest Canadian Devonian section of which we have any very definite knowledge,[1] appears to have no strong points of resemblance, either lithologic or faunal, to the southeastern Alaskan section.

A few other localities besides those mentioned have furnished small collections of Devonian fossils. The small number of well-known species, or the poor state of preservation of the material from these localities, makes it undesirable to offer an opinion as to the horizons represented without considerable reservation. In one of these lots, which was collected from limestone beds on the south side of Kosciusko Peninsula, are crinoid stems, *Spirorbis* sp., *Atrypa* sp., *Cyrtina* cf. *billingsi* Meek, *Meristella* cf. *barrisi* Hall, *Cranaena* cf. *romingeri* Hall, *Orthis* cf. *arcuata* Phillips, *Pleurotomaria* sp.

Devonian fossils have been reported also from Kuiu Island by Professor Charles Schuchert.[2] In describing a collection obtained by Dall and Becker from Saginaw Bay, Kuiu Island (8), he states that they "unmistakably indicate the presence there of Carboniferous and Devonian strata."[3] A careful examination of the locality from which Schuchert's fossils came failed to discover any Devonian horizon. Recently the fossils which were considered Devonian by

[1] Canadian Geological Survey, *Contributions to Paleontology*, Vol. I, Part 3 (1891), p. 250; *Transactions of the Chicago Academy of Science*, Vol. I (1867–69), pp. 61–114, pls. 11–15.

[2] *Professional Paper No. 1*, U. S. Geological Survey, 1902, p. 43.

[3] *Seventeenth Annual Report*, U. S. Geological Survey, Part 1, p. 902.

Schuchert have been re-examined by Dr. Girty and the writer. They comprise specimens representing five or six species, most of which are common in the Upper Carboniferous fauna of Alaska. The specimens referred to *Conchidium* by Schuchert belong to the genus *Camarophoria* and are near, if not identical with, *C. margaritova*. This is a common and characteristic species of the Upper Carboniferous limestone in Alaska, not being known below it. *Spirifer* sp. undet. I is identical with a *Spirifer* collected from Carboniferous beds of Saginaw Bay by the writer, which Girty considers closely allied to *Sp. alatus* Schl. *Spirifer* sp. undet. II of Schuchert is represented only by a portion of the ventral valve, which is considerably worn. It shows traces of fine plications alternating with the seven or eight very coarse plications marking the surface. The one in the sinus is quite distinct. These minor plications distinguish it quite sharply from *S. arrecta*, with which it was compared, as well as from other Devonian brachiopods with which the writer is acquainted. The *Chaetetes* sp. undet. is probably a *Stenopora*. These supposed Devonian fossils all belong unquestionably to the Upper Carboniferous.

CARBONIFEROUS

The oldest Carboniferous fauna which has been found in southeastern Alaska was obtained at Freshwater Bay, in the northeastern part of Chichagof Island. This fauna was submitted to Dr. George H. Girty, who states, in a report furnished the writer, that, "while not unlike the American Lower Carboniferous or Mississippian, it resembles, and probably should be correlated with, the Russian Lower Carboniferous or *Productus giganteus* zone, or Mountain limestone." Freshwater Bay is the only locality visited where the Lower Carboniferous fauna has been found in southeastern Alaska. This locality is important also because the stratigraphic relation of the Lower Carboniferous to the older rocks may be observed.

On the northeastern side of the bay, and opposite the Silurian and Devonian limestones already described, the Carboniferous limestones form a low, narrow peninsula, never more than a few hundred yards in width, projecting out 4 miles from the mainland. The strike varies from N. 35° E. to N. 40° W., but generally has a northwesterly

and southeasterly trend. The dip is high, frequently 90°. It is sometimes easterly, and sometimes westerly, the direction of dip depending on whether or not the limb of the large fold to which all this peninsula and the older beds on the south side of the bay belong is slightly overturned at any given point. The thickness of the several divisions of the limestones which are exposed along the north shore of this peninsula is indicated approximately in the following section, which begins about one-half mile above (northwest of) North Passage Point (2):

	Feet
e. Breccia of large gray limestone fragments	100
d. Hard gray limestone, much fractured by numerous irregular joints, and breaking into small irregular fragments on weathering. Large *Productoids* common. Dip 30° to 90° toward southwest; strike N. 40° W. . .	90
c. Gray limestone with frequent bands of black chert. Fossils scarce. Strike N. 10° to 20° W. Dip 80° to 90° N. E.	275
b. Dark gray limestone with black chert bands. Fossils abundant near upper and lower limits. Average strike N. 30° E. Dip 70° to 80° N. W.	250
a. Limestone similar to *b.* Corals common	275
	990

Exposures on the north side of the bay and just west of the peninsula, which are lower but not continuous with this section, would add, if included in it, several hundred feet to its thickness. The total thickness of the Lower Carboniferous section is probably not less than 1,500 feet.

The following list, furnished by Dr. Girty, includes the more common species in the Lower Carboniferous beds at Freshwater Bay:

Zaphrentis sp.
Crinoid fragments
Diphyphyllum sp.
Productus giganteus Martin
Productus punctatus Martin ?
Productus aff. P. inflatus McChes.
Spirifer aff. S. trigonalis Martin
Cleiothyris aff. suborbiculoides McChes.

The Lower Carboniferous in southeast Alaska, while representing a different facies from that of the Mississippi Valley, is still much more closely allied to the Interior continental faunas than is the Upper Carboniferous fauna of this region. The Lower Carboniferous fauna is widely distributed in Alaska. If has been recognized as far north

as Cape Lisburne, on the Arctic coast,[1] and it occurs at numerous points on the Yukon and Porcupine Rivers in eastern Alaska.

Concerning the interval between the Upper and Lower Carboniferous faunas in this region we have but few data. No fauna representing it has been found.

The younger of the two Carboniferous faunas of southeastern Alaska is well represented in the limestones about Pybus Bay, on the southeast side of Admiralty Island (7), where they outcrop extensively along both arms of the bay. The limestones characterized by this Upper Carboniferous fauna have a thickness of about 600 feet at Pybus Bay. These Upper Carboniferous limestones are generally heavy-bedded or massive, as shown in the photograph (Fig. 2). The Lower Carboniferous limestones where observed have thinner bedding and are darker-colored than those of the higher horizon.

The following section, taken along the west shore of the east arm of the bay, indicates the character of the Carboniferous limestone (*c* of the section), and the associated beds:

		Feet
g.	Black to dark-gray argillaceous slates	300
f.	Covered interval	100
e.	Massive or heavy-bedded, gray limestone, with conchoidal fracture	40
d.	Light-gray limestone full of small, angular, cherty masses	80
c.	Light-gray cherty limestone in 10″ to 30″ bands, fossils abundant	600
b.	Red chert in 6″ to 20″ bands	300
a.	Black chert in 4″ to 10″ bands, with rarely a brown or red band	550
		1,970

The Mesozoic beds are represented by the two divisions *e* and *g* of the section. Whether the shales and the Mesozoic limestone are conformable or not, the section does not show, but the latter and the Carboniferous limestone are unconformable. The total thickness of the black slates cannot be determined from the outcrops which continue beyond the end of this section, since they belong to a series of low folds which do not bring the entire thickness of the beds to view. Other outcrops, however, just outside the bay indicate a total thickness of not less than 900 feet for these black slates, which have been referred provisionally to the Lower Cretaceous by Dr. Stanton, on account of the occurrence in them of a Cretaceous type of ***Aucella***.

[1] *Bulletin No. 278*, U. S. Geological Survey, pp. 22–25.

The fauna of the Pybus Bay limestone is the same which has been previously referred to the Permian in Alaska. Dr. George H. Girty, to whom the writer is indebted for the determination of the horizons represented by the Carboniferous collections, states, however, that he finds

that a greater resemblance exists with the Gschelian stage of the Russian section than with the Russian Permian. Provisionally, therefore, I will correlate this horizon with the Gschel-stufe, in which occur a great number of equivalent or identical species. This fauna is entirely unlike anything in the Mississippian province of the United States, but some of our western faunas resemble it.

Fossils are usually abundant and well preserved wherever the Upper Carboniferous limestone is found. The character of this fauna is shown by the following list of the species collected at Pybus Bay, which has been furnished by Dr. Girty:

Zaphrentis ? sp.
Fenestella sp.
Rhombopora sp.
Derbya sp.
Productus aff. P. gruenewaldti Krot
Productus aff. P. humboldti D'Orb
Productus aff. P. timanicus Stuck
Productus aff. P. lineatus Waagen
Productus aff. P. mammatus Keys.
Productus sp.
Rhynchopora aff. R. geinitziana Tscherny.
Spirifer arcticus Houghton
Spirifer aff. S. allatus
Spirifer n. sp. aff. S. marcoui
Spirifer n. sp. aff. S. dieneri Tscherny.
Squamularia sp.
Hustedia sp.
Spiriferina aff. S. cristata Schlot.
Cleiothyris sp.
Camarophoria margaritovi Tscherny.
Camarophoria aff. C. purdoni Davidson
Dielasma sp.
Cryptacanthia aff. C. compacta W. & St. J.
Aviculipecten sp.

In the faunas of the Halleck Harbor section Dr. Girty reports both the upper and lower series of the Gschel-stufe or upper Carboniferous faunas to be represented. This section, which is located on the north side of Saginaw Bay, Kuiu Island, follows:

		Feet
b	Light-gray limestone, locally cherty; fossils abundant	450±
a.	Black carbonaceous shales, with interbedded, dark, calcareous sandstones, arranged in belts, in which shales and sandstones alternately predominate	125+

At one point the shales and sandstones of division *a* are seen to pass along the bedding directly into cherts similar to those of Pybus

Bay. The fauna of this lower division of the section comprises the following species:[1]

Fusulina aff. F. longissima Moell.	Spirifer aff. S. ufensis Tscherny.
Crania sp.	Spirifer cameratus Tscherny. non Martin ?
Schizophoria ? sp.	Squamularia n. sp.
Derbya aff. D. robusta Hall	Martiniopsis sp.
Chonetes sp.	Rhynchopora aff. R. geinitziana Tscherny.
Chonetes aff. C. trapezoidalis Waagen	Dielasma sp.
Productus aff. P. humboldti D'Orb.	Streblopteria sp.
Productus aff. P. porrectus Kut.	Aviculipecten aff. A. mccoyi M. and H.
Productus aff. P. semireticulatus Martin	Aviculipecten, 2 spp.
Productus aff. P. schrenki Stuck	Entolium aff. E. aviculatum Meek.
Productus aff. P. koninckianus Vern.	Solenopsis ? sp.
Productus cora D'Orb	

In the upper division, *b*, occur the following species:

Zaphrentis ? sp.	Spirifer aff. S. alatus Schlot.
Stenopora sp.	Spirifer aff. S. blasii Vern.
Crinoid fragments	Spirifer arcticus Houghton
Streptorhynchus aff. S. pelargonatum Schlot.	Spirifer n. sp. aff. S. marcoui Waagen
Chonetes, 2 spp.	Spirifer aff. S. dieneri Tscherny.
Productus aff. P. timanicus Stuck.	Spiriferina aff. S. cristata Schlot.
Productus aff. P. aagardi Toula.	Squamularia sp.
Productus aff. gruenewaldti Stuck.	Cleiothyris sp.
Productus aff. P. humboldti D'Orb.	Camarophoria margaritovi Tscherny.
Productus aff. P. mammatus Keys.	Camarophoria aff. C. purdoni Davidson
Productus aff. P. lineatus Waagen	Rhynchopora aff. R. nikitini Tscherny.
Productus aff. P. occidentalis Newberry	Rhynchopora aff. R. geinitziana Tscherny.
Productus sp.	Dielasma sp.

Professor Schuchert published some notes on a collecton of Carboniferous fossils from a locality near this section in 1896. The fossils were referred to Schuchert by Dr. Dall and Mr. J. A. Becker, and were collected near Point Cornwallis, which is about one mile from Halleck Harbor. Two of these, *Spirifer* sp. undet. and *Productus longispinus* var. *alaskensis* Schuchert, are reported to come from a yellow sandstone. The appearance of the fossils indicates that they came from a siliceous band in the limestone of the section.

[1] Determined by Dr. G. H. Girty.

There appears to be no yellow sandstone member in the Saginaw Bay section. The remainder of the fossils reported by Schuchert are from a sandstone, "burnt-umber in color," which probably represents a portion of division *a* of the above section. The fossils reported by Schuchert from this "burnt umber" sandstone are:

Productus sp. undt. A	Spirifer duplicicostatus Phillips
Productus sp. undt. B	Spirifer pinguis Sowerby
Orthothetes crenistria (Phillips)	Spirifer condor d'Orbigny

The Upper Carboniferous limestone is terminated above by a Mesozoic limestone which rests unconformably on it. It is separated from the Lower Carboniferous series of Freshwater Bay by a series of cherts, dark shales, and sandstones of undetermined thickness. This limestone has a wide distribution in Alaska. In southeastern Alaska it is known on Admiralty, Kuiu, and Kupreanof islands. In the interior of Alaska the fauna of this limestone has been found in the Copper River basin by Mendenhall and Schrader,[1] and in the White River basin by Brooks.[2] The same fauna occurs on the Yukon, at the mouth of Nation River, nearly 700 miles northwest of the Kuiu Island and Pybus Bay localities. It has not been found, however, north of the Arctic circle. It is absent from the collections of both Collier[3] and Schrader[4] from northern Alaska. The writer found no trace of it in the Porcupine River section in northeastern Alaska.

In the United States the formation bearing the nearest resemblance faunally and stratigraphically to the Upper Carboniferous limestone of southeastern Alaska is the McCloud limestone of northern California. In a report on a collection of fossils from the McCloud limestone published by Mr. Diller attention is called to the similarity of the two faunas by Dr. Girty, who suggests that it is such "as to indicate the extension of this fauna and possibly of the earlier Carboniferous faunas of the California province to this region."[5] The thickness of the McCloud limestone has been estimated at from 1,000[6]

[1] *Professional Paper No. 15*, U. S. Geological Survey, 1903, p. 46.

[2] *Twenty-first Annual Report*, U. S. Geological Survey, Part 2, 1900, p. 359.

[3] *Bulletin No. 278*, U. S. Geological Survey, 1906, pp. 22–26.

[4] *Professional Paper No. 20*, U. S. Geological Survey, 1904, pp. 70, 71.

[5] *American Journal of Science*, Fourth Series, Vol. XV (1903), p. 351.

[6] *Geology of California*, Vol. I, p. 326.

to 2,000[1] feet. A thick series of shales and sandstones, with some conglomerates and calcareous lenses, underlies it.[2] Its nearest faunal relationship, like that of the Alaskan Upper Carboniferous limestone, is with the European and Asiatic province. The McCloud limestone has generally been regarded of Upper Carboniferous age.[3] By Tschernyschew it is correlated with the Upper Carboniferous or Uralian of Russia.[4]

It is very probable that representatives of the Upper Carboniferous limestones of Pybus Bay and Kuiu Island will be found in the Cache Creek[5] series of British Columbia. The data thus far published on these rocks show only that a considerable thickness of Carboniferous limestones[6] is present in British Columbia.

SUMMARY

The Silurian is represented by a limestone series probably 3,000 feet thick, holding faunas whose nearest equivalents in eastern America are the Niagaran and Guelph faunas. A series of beds aggregating several thousand feet in thickness precedes the beds known to be of Silurian age, and represents either Silurian or earlier horizons.

Lower, Middle, and Upper Devonian faunas are present in southeastern Alaska, the first resting upon beds of igneous origin. The total thickness of the Devonian is unknown. In the northern part of the region the Upper Devonian appears to be represented in part by beds of igneous origin. A limestone series about 470 feet in thickness forms the lowest lithologic series of the Devonian. *Spirifer disjunctus* and *Productella hallana* Wal. characterize the Upper Devonian fauna. Two species of *Hercynella* are the most abundant forms in the basal Devonian.

Limestones resembling somewhat the Mississippian in their fauna represent the Lower Carboniferous. These have a thickness of about

[1] *Journal of Geology*, Vol. II, p. 600. [2] *Ibid.*

[3] *Paleontology of California*, Vol. I, pp. 326, 327; *Journal of Geology*, Vol. II (1894), pp. 600, 601.

[4] *American Journal of Science*, Fourth Series, Vol. XXII (1906), p. 39; *Mémoire du Comité géologique*, Vol. XVI (1902 [1903]), pp. 433–51.

[5] *Bulletin of the Geological Society of America*, Vol. XII (1900), p. 70.

[6] *Ibid.*, p. 71.

1,500 feet. The highest member of the Paleozoic section in southeastern Alaska is a limestone of Upper Carboniferous age, probably the equivalent of the Gschel-stufe. At the only locality where the top of the Upper Carboniferous has been definitely located a limestone of Mesozoic age rests unconformably upon it. A series of beds, mostly limestones, having a thickness of not less than 800 feet, represents the Upper Carboniferous portion of the section.

The several faunas show comparatively little resemblance to the faunas of eastern America, while the similarity to the European and Asiatic faunas is in some cases very marked.

CONTRIBUTIONS TO THE PLEISTOCENE FLORA OF NORTH CAROLINA[1]

EDWARD W. BERRY
Johns Hopkins University

INTRODUCTION

During the summer of 1906, while engaged in a geological reconnaissance in North Carolina under the auspices of the Geological Survey of that state, two very interesting plant-beds of Pleistocene age were discovered, from which about forty different species of plants were collected. It is planned to describe and to fully illustrate these, together with future collections which it is hoped will be made, in a systematic volume devoted to the fossil remains of North Carolina; but, since it will be several years before this plan can be consummated, it seems desirable to publish a brief preliminary account of these plants, in so far as they have been determined, because of their by no means inconsiderable interest. To the geologist their chief interest is their bearing upon Pleistocene climates and their circumstantial evidence as to the very slight lapse of time, from a geological point of view, since glacial conditions came to a close. For the botanist they tend to show that some of the main elements in our present coastal plain flora, especially the arborescent forms, were already well defined in Pleistocene times, and that, while very likely a considerable part of the endemic herbaceous flora of the coastal plain has been differentiated in postglacial times, this theory cannot be extended to include many of the arborescent forms. The bulk of the following species are from a deposit on the Neuse River in Wayne County which I regard as of estuarine origin, laid down in post-glacial times, although it is quite possible that we have to deal with river deposits.[2]

[1] Published by permission of the North Carolina Geological Survey.

[2] Marine Pleistocene fossils occur near the mouth of the Cape Fear River, and an abundant marine fauna of Pleistocene age has been obtained from several artesian wells in New Hanover and Brunswick counties.

The assumptions on the part of the writer are drawn from the analogy of the Maryland and South Carolina Pleistocene, where an abundant marine fauna has been found. The locality along the Roanoke River will be referred to as Old Mill, and that on the Neuse River as station 850, the latter shown on the United States Engineers' blueprint map of the Neuse River. Citations will be made only of fossil occurrences.

ENUMERATION OF SPECIES

SPERMATOPHYTA

GYMNOSPERMAE

Coniferales

PINUS RIGIDA Mill.

Penhallow, *Transactions of the Royal Society of Canada*, Vol. X (1904), sec. 4, p. 69.

Characteristic leaves of this species, which are stout and stiff, some of them still in fascicles of three with the sheaths preserved, occur at station 850.

In the modern flora this species ranges from New Brunswick to Georgia, and west to Ontario and Kentucky, in dry sandy or rocky soil. It is a dominant form in the so-called "pine barrens" of New Jersey, and ranges farther north than do most of the members of the North Carolina Pleistocene flora. Wood has been recorded by Penhallow (*loc. cit.*) from a well-boring at Ithaca, N. Y.

The European Pleistocene contains several species based on foliage, cones, seeds and wood. In America *Pinus strobus* L. has been recorded from New Brunswick and Maryland, and *Pinus echinata* Mill from Maryland.

TAXODIUM DISTICHUM (L.) L. C. Rich.

Holmes, *Journal of Elisha Mitchell Society* for 1884-85, p. 92 (1885).

Berry, *Torreya*, Vol. VI (1906), p. 89.

Hollick, Maryland Geological Survey, *Pliocene and Pleistocene* (1906), p. 218, Plate 68.

Cypress swamps seem to have been a feature of the Pleistocene of the Atlantic coast. Several such, with stumps, knees, cones, and seeds, have been described from Maryland, and I am able to record another from near Rehobeth, Dela.[1]

[1] Communicated by Dr. C. K. Swartz.

Holmes (*loc. cit.*) records stumps up to six feet in diameter in a dark stiff clay beneath 18–20 feet of loam, laminated sands and clays, and marls, a few miles below New Bern on the Neuse River.

At station 850 were found many twigs and detached seeds. At Old Mill the twigs are common, and a rather poor cone impression was collected together with an unmistakable staminate ament.

ANGIOSPERMAE

Juglandales

HICORIA GLABRA (Mill) Britt.

Berry, *Torreya*, Vol. VI (1906), p. 89.

Occurrence based on a flattened nut and several husks from station 850. This species has been previously recorded from the Pleistocene of Virginia (nuts), and a small nut not specifically determined is recorded by Hollick from Maryland. The latter author also describes leaves of apparently this species under the name of *Hicoria pseudo-glabra* from the basal Pleistocene (Sunderland) of Maryland.

HICORIA OVATA (Mill) Britt.

Determination based on two incomplete terminal leaflets from station 850 which resemble this species more closely than they do those of any other modern hickory. In the living flora this species ranges from Quebec to Florida.

HICORIA SP. cf. *microcarpa* (Nutt.) Britt.

A hickory nut of larger size, much flattened and with a thin, apparently tardily dehiscent, husk was found at station 850. As yet it has not been satisfactorily correlated with any of the existing species.

Salicales

SALIX SP.

A single leaf of a willow was found at station 850. It has not been possible to satisfactorily determine its specific relations. The poplars which are well represented by three species of leaves in the Maryland Pleistocene have not yet been found in North Carolina.

Fagales

CARPINUS CAROLINIANA Walt.

Represented by numerous leaves from station 850. Similar remains are recorded from the basal Pleistocene of Maryland by

Hollick under the name *Carpinus pseudo-caroliniana*. The living *Carpinus orientalis* L. K. and *betulus* L. have been recorded from the Italian Pleistocene.

BETULA NIGRA L.

Knowlton, *American Geologist*, Vol. XVIII (1896), p. 371.

This species was very common at station 850, the remains including many leaves and some fragments of bark. Leaf impressions were also common in the clays at Old Mill. Recorded by Knowlton (*loc. cit.*) from the glacial terraces at Morgantown, W. Va.

The genus first appears in the Dakota sandstones, occurring also in the higher Cretaceous of North America and Greenland. It is largely developed in the Eocene, with over a dozen American species, the first European forms occurring at this horizon. Abundantly represented by numerous species in the Oligocene, Miocene, and Pliocene. Of the living forms *Betula lutea* Michx. has been recorded from the American, and *Betula nana* L. and *alba* from the European Pleistocene.

BETULA PSEUDO-FONTINALIS sp. nov.

Leaves in appearance very similar to those of the western *Betula fontinalis* of Sargent occur at station 850. The name given implies nothing more than the resemblance in leaf-form. This species may be characterized as follows: leaves ovate, with a broad truncate or rounded entire base; unusually long petiole and sparse secondary venation; margin indifferently serrate or dentate above.

FAGUS AMERICANA Sweet.

Berry, *Torreya*, Vol. VI (1906), p. 88.
Hollick, Maryland Geological Survey, *Pliocene and Pleistocene* (1906), p. 226.
Fagus ferruginea (Michx.) Lesq.: *American Journal of Science*, Vol. XXVII (1859), p. 363; *Geology of Tennessee* (1869), p. 427, Plate 7 (K), Fig. 11. *Fagus ferruginea* Ait.: Knowlton, *American Geologist*, Vol. XVIII (1896), p. 371.

Leaves, nuts, and husks of this species are common at station 850. The beech is one of the commonest Pleistocene forms, and leaves, nuts, or husks have previously been recorded from both the oldest (Sunderland) and the youngest (Talbot) Pleistocene formations of Maryland, and from the Pleistocene of Tennessee, Virginia, and West Virginia.

QUERCUS PHELLOS L.

Leaves of the willow oak are common at station 850.

QUERCUS ALBA L.

Penhallow, *Transactions of the Royal Society of Canada*, Vol. X (1904), sec. 4, p. 74.

The leaves of the white oak are fairly common at station 850. Both leaves and wood are recorded by Penhallow from the Don River beds of Canada, and probably the same species under the name of *Quercus pseudo-alba* is recorded by Hollick from the Sunderland of Maryland.

QUERCUS LYRATA Walt.

Several leaves, together with four characteristic specimens of the acorns, of this species were found at station 850.

QUERCUS PALUSTRIS Du Roi.

Occurrence based on leaves from station 850.

QUERCUS PREDIGITATA sp. nov.

Leaves of the type of those of the Spanish oak—to which, however, it has seemed best to give a new name, since it is very probably the ancestral form, not only of this species, but of *Quercus pagodaefolia* (Ell.) Ashe as well—are abundantly represented at station 850. The leaves show gradations between *digitata* and *pagodaefolia*. Probably the same species is recorded by Knowlton from the glacial terraces at Morgantown, W. Va., under the old name *Quercus falcata* Michx.

QUERCUS ABNORMALIS sp. nov.

An abnormal oak leaf, bifid, with two linear lobes about one inch across. Based on a single specimen with the characteristic venation of *Quercus* from station 850. Leaf narrow, elongated, coriaceous; the blade divided about half-way up into two divergent lobes; margins entire.

QUERCUS MARYLANDICA Muench.

Several leaf specimens were collected at station 850.

QUERCUS NIGRA L.

Several leaf specimens from station 850.

QUERCUS PRINUS L.

Leaves fragmentary for the most part, but common, station 850.

QUERCUS PLATANOIDES (Lam.) Sudw.

Several leaf specimens from station 850. It is, of course possible —I might say, probable—that the leaves of this and the preceding represent the variable leaves of their common Pleistocene ancestor, not yet differentiated into dry and moisture loving forms.

QUERCUS PRINOIDES Willd.

Leaves which apparently represent this species occur at station 850, although it is impossible to determine their exact relation to the two preceding forms.

ULMUS ALATA Michx.

Several leaves of this modern southern type were found at station 850. Two species of *Ulmus* are known from the Sunderland of Maryland; *Ulmus betuloides* Hollick, possibly representing the modern *Ulmus americana* L., and *Ulmus pseudo-racemosa* Hollick, representing the modern *Ulmus racemosa* Thomas. The latter also occurs at Morgantown, W. Va., and in the Don River deposits of Canada, where it is associated with *Ulmus americana*.

PLANERA AQUATICA (Walt.) J. F. Gmelin.

This southern type in the modern flora is represented by two or three rather unsatisfactorily determined leaves from station 850. The related, if not identical *Planera ungeri* Ettings is recorded from the Sunderland of Maryland.

Ranales

BERBERIS SP.

A single leaf, apparently a barberry, but not specifically determinable, was found at station 850.

Rosales

LIQUIDAMBAR STYRACIFLUA L.

Hollick, *Bulletin of Torrey Club*, Vol. XIX (1892), p. 331.

Knowlton, *American Geologist*, Vol. XVIII (1896), p. 371.

Liquidambar europaeum Al. Br., Lesq.: *Proceedings of U. S. National Museum*, Vol. XI (1888), p. 36.

The sweet or red gum is sparingly represented at station 850 by two or three fragmentary leaves and one flattened fruit-head. Previously recorded from Morgantown, W. Va., by Knowlton, and from Bridgeton, N. J., by Lesquereux and Hollick. I should expect this

species to be more common in the North Carolina Pleistocene than it is. Its rarity, however, may be one of the exigencies of preservation, since I have noticed that the modern gum leaves decay much more rapidly than do most other leaves, judging by their comparative state of preservation in the recent leaf-rafts and leaf-beds along the North Carolina rivers.

PLATANUS OCCIDENTALIS L.

Knowlton, *American Geologist*, Vol. XVIII (1896), p. 371.

Penhallow, *Transactions of the Royal Society of Canada* (II), Vol. II (1896), sec. 4, pp. 68, 72.

Platanus aceroides Göpp.: Hollick, Maryland Geological Survey, *Pliocene and Pleistocene* (1906), p. 231, Plates 73, 74.

Fragmentary leaves of this species were common, and one flattened "buttonball" was found at station 850.

This seems to have been one of the common types of the Pleistocene. Recorded from the Sunderland, or oldest Pleistocene, of Maryland, as well as in the interglacial Don River deposits of Canada and the glacial terraces at Morgantown, W. Va. The Carolina leaves average somewhat smaller than do those of the modern tree.

RUBUS SP.

Based on a small branch with characteristic prickles, found at station 850.

MALUS CORONARIAFOLIA sp. nov.

Leaves triangularly ovate with acute apex and rounded base, 4^{cm} by 3.1^{cm}, with four or five incised lobes on each side, the margins finely salient-serrate. Based on leaves very like those of the American crab apple, *Malus coronaria* (L.) Mill, found at station 850. Besides these leaves there are others somewhat resembling the modern *Malus angustifolia*, but not yet positively determined.

CRATAEGUS SPATHULATOIDES sp. nov.

Based on leaves like those of the modern small-fruited haw, *Crataegus spathulata* Michx; which they resemble so closely that further specific characterization is unnecessary. Collected at station 850.

CRATAEGUS COCCINEAFOLIA sp. nov.

Based on leaves and thorns preserved in the lignitic layers, and so like those of the modern scarlet thorn, *Crataegus coccinea* L., that further specific characterization is unnecessary at this time.

It is probable that both this and the preceding still exist, but since the modern thorns have been segregated into such a maze of species, it was not thought profitable to attempt any closer identification of these two Pleistocene forms.

Sapindales

ILEX OPACA Ait.

Hollick, *Bulletin of Torrey Club*, Vol. XIX (1892), p. 331.

Based on two characteristic leaves from station 850. Recorded by Hollick along with *Ilex cassine* L. from Bridgeton, N. J.

The genus is an old one, ranging back to the Mid-Cretaceous, and apparently somewhat composite in character. A species of the Prinos section is recorded from the Pleistocene of Kentucky, and the genus is also represented in the European Pleistocene.

Rhamnales

VITIS SP.

This occurrence is based on a tendril preserved at station 850.

Grapes were apparently common during the Pleistocene, although heretofore represented only by their very characteristic seeds, which have been recorded by the writer from the Virginia Pleistocene, and by Hollick from four different localities in the Maryland Pleistocene. Two Pleistocene species are recorded from Europe.

Thymeleales

PERSEA PUBESCENS (Pursh) Sargent.

This southern swamp form is represented by two leaves from station 850.

Umbellales

NYSSA BIFLORA Walt.

Berry, *Torreya*, Vol. VI (1906), p. 90.

Hollick, Maryland Geological Survey, *Pliocene and Pleistocene* (1906), p. 235, Plate 69, Fig. 5.

Nyssa caroliniana Poir: Hollick, *Bulletin of Torrey Club*, Vol. XIX (1892), p. 331.

North Carolina representation includes leaves from station 850 and seeds from Old Mill. Previously recorded from the late Pleistocene of Virginia and Maryland, being represented by both leaves and seeds in the latter state. Leaves have been recorded from Bridgeton, N. J., and the writer has recently collected the seeds in the clays at Fish House, N. J.

Ericales

XOLISMA LIGUSTRINA (L.) Britt.

Hollick, Maryland Geological Survey, *Pliocene and Pleistocene* (1906), p. 236, Plate 69, Fig. 6.

Fossil forms of this type of leaf are usually referred to the genus *Andromeda* of Linnaeus, and many species are recorded, ranging from the Mid-Cretaceous to the present. Lesquereux records two species (*dubia* and *vaccinifoliae affinis*) from the Pleistocene of Somerville, Tenn. The present species was found at station 850. It has been previously recorded from the late Pleistocene (Talbot) of Maryland.

DENDRIUM PLEISTOCENICUM sp. nov.

Based on leaves from station 850. They are of coriaceous texture, and are identical with those of *Dendrium hugeri*, which has been separated by Small from the old species *Dendrium buxifolium* (Berg.) Desv., in which the leaves are smaller.

It seems likely that the modern *Dendrium hugeri*, which is a form of the mountains of western North and South Carolina, is directly descended from this Pleistocene form, and that *Dendrium buxifolium*, which is a "pine-barren" form with reduced leaves, and which ranges from New Jersey to Florida, is a later specialization in that habitat.

VACCINIUM CORYMBOSUM L.

Hollick, Maryland Geological Survey, *Pliocene and Pleistocene* (1906), p. 236, Plate 69, Figs. 7–9.

Specimens of leaves of this species occur both at station 850 and at Old Mill. Previously recorded from the late Pleistocene (Talbot) of Maryland.

VACCINIUM SPATULATA sp. nov.

Based on spatulate leaves of this generic type found at station 850. Length 2.4^{cm}, width 1.2^{cm}. Somewhat coriaceous with two or three remote camptodrome secondaries on each side.

CONCLUSIONS

Attention is arrested by the remarkable development of the oaks in this flora, there being eleven species in all, or nearly 29 per cent. of the known flora; and if it be objected that some of the determinations, such as the recognition of *prinus*, *prinoides*, and *platanoides*, will not stand, there still remains an unusually large showing, possibly to be explained by the fact that oak leaves are more coriaceous and resist maceration better than do most leaves.

It will be seen at a glance that the enumerated flora as given above contains no boreal or even cool temperate elements. All of the species which in the modern flora range northward into New England or Canada also range southward to Georgia and Florida, with but two exceptions—*Pinus rigida*, whose present southern range is Virginia, and *Quercus prinoides*, whose present southern limit is North Carolina. Southern Delaware and Maryland mark the northern limit of *Taxodium distichum;* New Jersey marks the northern limit of *Quercus lyrata*, *digitata*, *nigra*, *Nyssa biflora*, and *Dendrium;* while *Quercus phellos* and *marylandica* do not get beyond Long Island, and *Liquidambar* dies out in Connecticut. On the other hand, *Ulmus alata* does not get north of Virginia, and *Persea pubescens* and *Planera aquatica* do not get north of North Carolina.

There are nine distinctly swamp and low river-bank forms, two additional forms of low moist woods besides *Liquidambar* and *Platanus*, which make their best growth in humid wooded regions. The forms which in the living flora are denizens of dry sandy or rocky soils are *Pinus rigida*, *Quercus phellos*, *digitata*, *nigra*, *prinoides*, and *marylandica*.

While it is always perilous to estimate the temperature in degrees from fossil faunas or floras, and it would be rash indeed to assert that, since some of these forms do not range above North Carolina in the living flora, the temperature of the Pleistocene in this region would have a minimum of 40° to 44°. However, from the floral grouping as a whole I think it may safely be concluded that the temperatures were not lower than they are at the present time in the same latitude, and, if anything, they were slightly higher, with as great humidity as prevails at the present time in the coastal plain of North Carolina.

These results agree with those arrived at by Pugh[1] from a study of the Mollusca from the Pleistocene of South Carolina. Additional facts pointing to the same general conclusion are the former northward extension of *Taxodium*, and the occurrence of *Planera aquatica* in the Pleistocene of Maryland. That these floras did not flourish in mild interglacial periods is indicated by their association in Maryland with ice-borne bowlders of considerable size, the origin of some of which has been traced, the direction of movement discrediting forces other than those of ice-action. A further fact is the occurrence of several of these species in the West Virginia glacial terraces. Some of these terraces contain remains of the musk-ox and other pronounced boreal types, and are undoubtedly of glacial origin. Those with fossil plants are not so satisfactory, as they contain few species of northern affinities, and might be taken to illustrate interglacial conditions, although they do not indicate as mild a climate as do the fossiliferous interglacial beds in the valley of the Don, near Toronto, Canada. These considerations somewhat weaken their evidence in this connection. They are here denominated as "glacial," following the original description by I. C. White and Knowlton, with the reservation that close stratigraphical studies may subsequently show that the plant-bearing terraces differ in age from those with boreal animal remains, as the contained flora in a measure indicates, although not altogether inconsistent with the published view of their glacial age.

To be sure, the North Carolina deposits were many miles south of the terminal moraine, and the local ice which may have been developed, while it proved equal to the task of transporting bowlders, did not exercise any considerable effect upon the temperatures of the lowlands. Cobb has suggested[2] that the cobbles found along the "banks" of the Carolina coast were transported by icebergs from New England during periods of maximum glaciation and are not of local origin. By implication this theory might include all the erratics in the marine Pleistocene of the southern coastal plain. Such a conclusion seems, however, extremely improbable.

[1] G. T. Pugh, *Pleistocene Deposits of South Carolina*, Thesis, Vanderbilt University, 1905.

[2] C. Cobb, *Journal of Elisha Mitchell Society*, Vol. XXII (1906), p. 18.

We know that the land was low and that the country was densely wooded, with a high humidity, all of which are factors that ameliorate temperatures, so that persistent ice in comparatively low latitudes, if present at all, seems to have been almost entirely a question of moderate cooling in the highlands, combined with unbalanced precipitation, while the climate of the low-lying coastal plain, even as far northward as Maryland, did not differ greatly from what it is at present.

THE GIRDLES AND HIND LIMB OF HOLOSAURUS ABRUPTUS MARSH

S. R. CAPPS, JR.
University of Chicago

The specimen described below, in the Paleontological Collection of the University of Chicago, was collected during the summer of 1903 by a University of Chicago paleontological expedition. The complete skeleton was discovered by Dr. E. B. Branson and collected by himself and Professor Williston. Thanks are due to Dr. Williston for permission to study this excellent specimen.

The specimen is of peculiar interest in that it is probably the most complete one of a mosasaur ever collected, almost every bone lying in its original position with relation to the rest of the skeleton. Furthermore, it belongs to the hitherto very imperfectly known form of *Holosaurus abruptus* Marsh, and the undisturbed condition of the skeleton offers an opportunity for clearing up a number of doubtful points. Besides this remarkable specimen, a complete pelvic girdle of the same species was found at the same time, with the bones spread out in their original relations to one another. From the study of these two specimens it was determined: (1) that the ilium lay below the third pygal vertebra, and not below the first, as usually figured, and that it had a nearly vertical position to the vertebral column, instead of having a strong backward slope; (2) that there was a firm symphysis of both the ischia and of the pubes, as shown by the position of these bones (Fig. 2); (3) that there was an interclavicle bone present (Fig. 1). The rear paddle of the mosasaur, moreover, has so far been very imperfectly known. It was figured by Marsh in 1880 for *Platecarpus*, and by Osborn much later for *Tylosaurus dyspelor*, but neither specimen was perfect, and both are of species different from that described below (Fig. 3).

The pectoral girdle of this specimen is very perfectly preserved (Fig. 1). Lying between the coracoids there was found a thin,

bladelike bone, the interclavicle. In 1880 Marsh[1] stated: "In *Holosaurus* there appears to have been a partially ossified mesosternum;" and in 1889 Dollo[2] mentioned the presence of an interclavicle

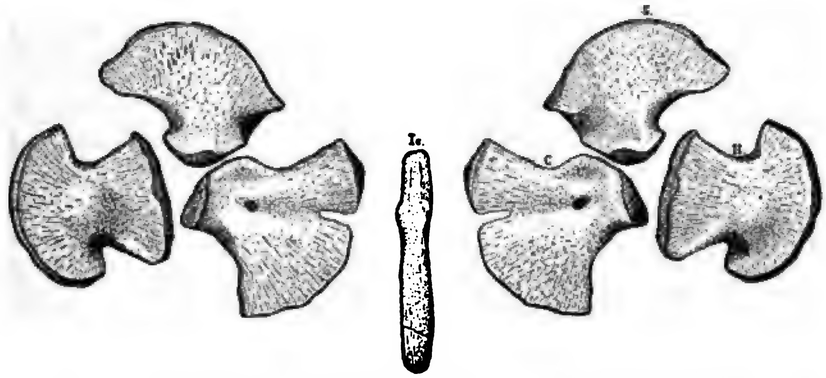


FIG. 1.—Pectoral girdle of *Holosaurus abruptus*. One-seventh natural size. *Ic*, interclavicle; *c*, coracoid; *s*, scapula; *H*, humerus.

in *Plioplatecarpus*. Williston[3] discovered the existence of this element in *Platecarpus* in 1899, but up to the present time it has never been figured. The interclavicle in this specimen is slender, rounded

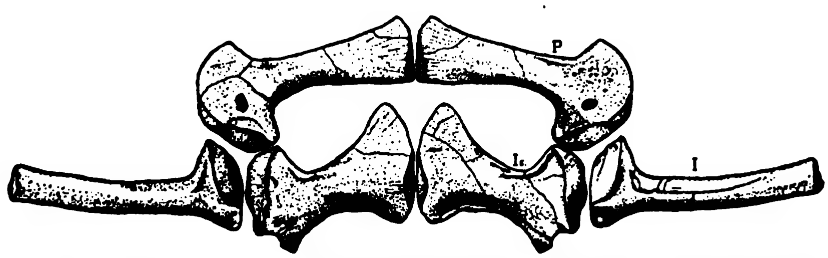


FIG. 2.—Pelvic girdle of *Holosaurus abruptus*. One-sixth natural size. *P*, pubis; *Is*, ischium; *I*, ilium.

laterally at both ends, and differs from that described for *Platecarpus* in that it has no apparent articular facets at the anterior end.

The calcified sternum of the specimen is preserved in the chalk, but no description of this will be attempted in the present article, as

[1] *American Journal of Science*, Vol. XIX (1880), p. 841.

[2] *Bull. Soc. Belg. Geol. Pal. Hyd.*, III (1889), 286.

[3] *Kansas University Quarterly*, Vol. VIII, No. I (January, 1899), p. 39.

considerable further study will be necessary for the proper working-out of this portion of the skeleton.

The *scapula* resembles very closely that of *Platecarpus ictericus*,[1] being thinned and flattened above, with a truncate margin for cartilaginous attachment. Below, the bone is thickened for articulation with the coracoid and humerus.

The *coracoid* also is remarkably like that of *Platecarpus*, the only essential difference being the less deep emargination. This species is referred with great certainty to *Holosaurus abruptus* by Williston after a careful examination of the type specimen in the Yale collection—a specimen which he himself collected. The emargination of the coracoid is therefore proven to be an individual, and not a generic character. The close resemblance of the different elements of the skeleton to that of *Platecarpus* make it seem certain that this specimen must ultimately be referred to that genus, but there are a number of differences between this specimen and any described species of *Platecarpus*. The name *Holosaurus abruptus* will therefore be used provisionally until the specimen is mounted and available for critical comparison.

The ilium.—The ilium is a shaftlike bone, expanded proximally. From the relation in which the bones of the two sides were found it is evident that the vertebral end was approximated in life to the end of the transverse process of the third pygal vertebra, though evidently not attached to it. The relations of the bones, as found, also show that the ilium had a nearly vertical position. Proximally the bone is expanded and thickened, with a continuous facet for articulation with the ischium and pubis, and for the acetabulum. The bone resembles most closely that of *Platecarpus*.

The ischium.—The ischium is a very broad, flat bone, laterally expanded at either end. The acetabular end has facets for articulation with the ilium and pubis, and an outwardly directed face for the acetabulum. Behind the acetabulum, and slightly separated from it, is a thin process with a roughened end for cartilaginous attachment. The shaft of the bone has a rounded, thickened ridge on its lower side, and is slightly concave above. The distal end has a very broad, thin lateral expansion in front. The shaft, at its thickened portion,

[1] *University Geological Survey of Kansas*, Vol. IV, p. 184.

shows a sub-triangular facet for a firm symphysis with the opposite ischium.

The pubis is much like that of *Platecarpus*. It is a thin bone, broadly rounded at the acetabular end, the posterior edge of which ends in facets for the acetabulum, and for articulation with the ilium and ischium. The pubic foramen is placed similarly to that of *Platecarpus*. The lower end of the bone is thin and somewhat expanded, and shows a roughened face for symphysis with the opposite pubis.

Femur.—The femur is a heavy, stout bone, somewhat expanded proximally and terminating along the whole upper border in an articular face which is thickened anteriorly and thinned posteriorly. The trochanter, on the anterior side, is directed upward and inward. The distal end of the bone is more expanded than the proximal, and has a much thickened oval face for articulation with the tibia, and a thinner one for the fibula.

Tibia.—The tibia is a short, stout bone, expanded and much thickened at the proximal end, and having a large, oval face for articulation with the femur. The anterior margin of the bone is deeply concave, and the posterior margin is longer, and less deeply concave. The distal end is fan-shaped, thinned anteriorly and posteriorly, and thickened centrally. It ends in a flat facet for articulation with the large tibial tarsal bone.

In Plate VII of Williston's work on the Mosasaurs,[1] Figs. 1 and 2 are referred to the radius of a doubtful species of *Platecarpus*, but these bones are doubtless tibiae of *Holosaurus abruptus*, to which genus they have already been referred by Williston.

Fibula.—The fibula is a thin, flat bone, expanded laterally at both ends. At the proximal end is the articulation for the femur, facing forward and upward. The anterior margin of the bone is concave throughout and is shorter than the strongly concave posterior margin. Distally the bone is fan-shaped, and bears articular faces for the two upper tarsals.

Tarsus.—The tarsus is composed of three bones, a large and two smaller, posterior to it, all of which are thin and flat. The large bone has two articular faces above, for the tibia and fibula, that for the

[1] *University Geological Survey of Kansas*, Vol. IV, Plate LVII.

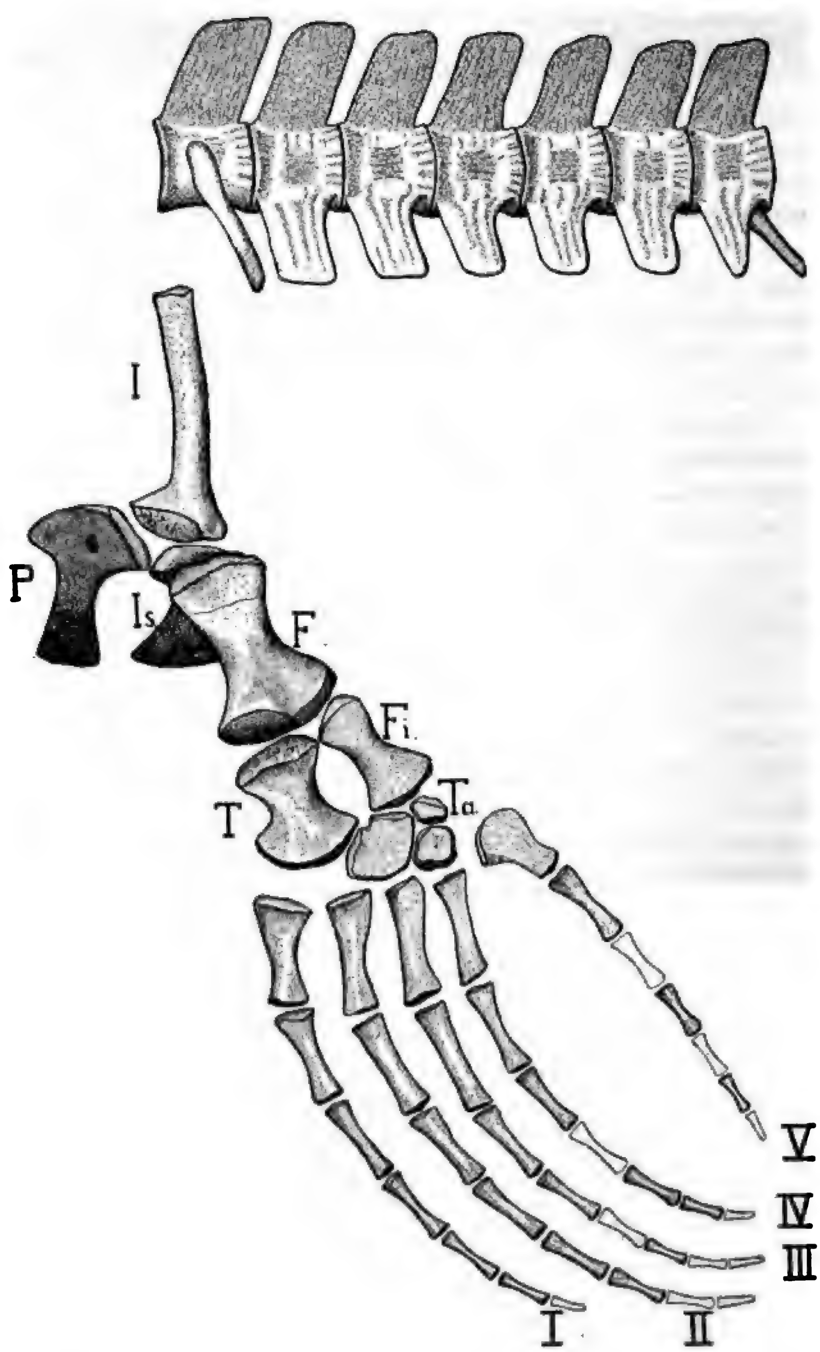


FIG. 3.—Hind limb of *Holosaurus abruptus*. One-fifth natural size. *I*, ilium; *P*, pubis; *Is*, ischium; *F*, femur; *T*, tibia; *F*, fibula; *Ta*, tarsus. Ilium found lying opposite the third pygal, the fourth vertebra of the series, as figured.

former sloping obliquely forward, and for the fibula obliquely backward, the two making an angle of something more than 90°. These two faces are separated by a rounded notch. The distal edge is a wide curve, and articulates with the second and third metatarsals and the other two tarsals. The two smaller tarsals lie one above the other, behind the large one. The upper one is the smallest, and articulates with the fibula, the other two tarsals, and the fifth metatarsal. The lower of the two smaller tarsals articulates with the other two tarsals, and with the fourth and fifth metatarsals.

Metatarsals.—The first metatarsal is a stout bone, broadly expanded and thickened proximally, with a large, flat surface for the tibial articulation. This face slopes obliquely backward. Toward the middle the bone is constricted, and the posterior margin is deeply concave, and is shorter than the more gently concave anterior margin. The distal end is slightly expanded and ends in a suboval, flat articular facet.

The second metatarsal is more slender than the first. Its proximal end is expanded laterally, with the anterior edge thicker than the posterior. The articular face is directed forward and upward. The anterior margin of the shaft is thick and only slightly concave, while the posterior margin is thinner and rather deeply concave in the center. The distal end is slightly expanded, and has a subtriangular articular face.

The third metatarsal is the longest of the five. Its somewhat expanded proximal end terminates in a suboval face for articulation with the largest tarsal bone. The anterior margin of the shaft is almost straight, while the posterior margin is deeply convex toward the distal end, which terminates in a backward sloping articular face. The two articular faces are subparallel.

The fourth metatarsal is smaller and more slender than the three preceding. Its proximal articulation slopes forward somewhat, and is subparallel with the backward-sloping distal articular face. The bone is somewhat expanded at both ends, and the concavity of the forward margin, though slight, exceeds that of the nearly straight posterior margin.

The fifth metatarsal is a thin, flattened bone, much expanded proximally. The proximal border is edged on the forward and

upper side, by a flat face for articulation with the two smaller tarsals. The inner border is thicker and less strongly concave than the shorter outer border. Distally, the bone is not one-half the width of the proximal end. It is somewhat thickened, and terminates in a convex articular face.

Phalanges.—The first finger has at least six, possibly seven, phalanges, all stout and of a slender hourglass shape. The inner margin has the greater concavity.

The second finger has seven phalanges, shaped much like those of the first finger, with the greater concavity on the posterior margin.

The third finger is of about equal length with the second, and probably had the same number of phalanges, but the bones are somewhat more slender. The posterior margin is more concave and shorter than the anterior.

The fourth finger has about six phalanges which were somewhat thinner and flatter than in the first three fingers. The greater marginal concavity is on the posterior side.

The fifth finger is thin and flat. There were five or six phalanges, all much wider than thick, with the greater concavity on the anterior side. This finger is considerably shorter than any of the others.

The bones of the hind limbs were somewhat intermingled, and partially disarranged, but a careful study of their positions as found in the chalk slab renders any other arrangement than the one given for all save the terminal bones practically impossible.

THE FORMATION OF LEUCITE IN IGNEOUS ROCKS
Continued

HENRY S. WASHINGTON

COMPARISON

In the preceding discussion we have dealt only with norms or ideal rocks, of simple chemical compositions, and with perfectly normative modes composed of a few standard minerals alone. In these the relations are purely chemical, and the order of affinity for silica has been assumed to be invariable. But we have now to consider igneous rocks as they actually exist in nature. In dealing with them the problem becomes much more complex, not only through the introduction of a greater number of chemical and mineral constituents, but on account of the presence of several factors, both intrinsic and extrinsic to the magma or the rock, which may greatly modify our assumedly invariable orders of affinity.

We must remember that few of the standard minerals present in rocks are ever as simple in composition as they are assumed to be in calculating the norm. Thus a purely potassic orthoclase seldom occurs, this mineral almost invariably containing varying, though often small, amounts of soda and lime. Similarly with albite and anorthite, which tend to crystallize together, as well as to contain frequently small quantities of the orthoclase molecule. Leucite usually carries small amounts of soda and lime, while modal nephelite is never a simple, purely sodic, orthosilicate, but invariably contains small percentages of potash, giving rise to a more complex formula. The development in very many rocks of the alferric augites, hornblendes, micas, and other minerals, with numerous chemical constituents and highly complex molecules, is also an important fact to be taken into consideration.

Again, the fact that the crystallization of minerals changes the composition of the remaining fluid portions of the magma must not be lost sight of, and finally the influence of such factors as the mass action of complex mineral molecules, the physical conditions of

cooling, the presence of mineralizers, and so forth, upon the order of affinity are all important elements in the problem. The list of these possibly disturbing factors is a long one, and the established facts of chemistry show that affinities which hold good, or reactions which take place, under certain conditions may be much modified or entirely altered under others.

Bearing these possibilities in mind, we may proceed to the comparison between the actual rocks and our assumed norms. This may be done by plotting the rocks on the same diagram as our theoretical areas, and observing the correspondences and divergences, for which we may again turn to Plate II (p. 270).

The rocks chosen for comparison embrace practically all those known to me which carry modal leucite, whether or not it is present in the norm, and those which show normative but not modal leucite. Some seriously altered rocks are omitted, and only rocks of which superior, trustworthy analyses exist, and of which the norms can be properly calculated, have been selected. With these are also plotted certain rocks which do not carry leucite either in the norm or in the mode, but which are high in potash, as well as a few which are not specially high in potash, but which belong to the same comagmatic regions as leucitic rocks, and are genetically connected with them. The list of the non-leucitic rocks could be increased very greatly, as they form the vast majority of all known rocks; but the plotting of an indefinitely large number would not aid the present discussion, so that only those few are chosen which fall near the leucitic areas or which seem to bear on the problem.

The analyses are taken from Roth's *Tabellen*, from my collection of rock analyses published between 1884 and 1900, from the recent paper on the rocks of the Roman Comagmatic Region, and from numerous analyses published since 1900, of which a collection is being made preparatory to the publication of a supplement to the first. A list of those plotted will be found in the Appendix.

Nearly all of these analyses are plotted on Plate II, the abscissa being the percentage of silica and the ordinate that of potash, both expressed molecularly. The following conventional signs are adopted: Black indicates a persalane rock, green a dosalane, and red a salfemane or dofemane rock. A circle denotes that leucite is present in

the norm, and a square that leucite is not present in the norm. A solid color denotes that leucite is present in the mode, and a simple outline with uncolored interior that leucite is not present in the mode. Thus a solidly colored circle shows that the rock contains leucite both in the norm and in the mode; a solidly colored square, that it contains no normative leucite, but that this mineral occurs modally; an uncolored circle, that, while the norm of the rock shows leucite, none of this has actually developed; and finally, an uncolored square, that the rock is not leucitic, either normatively or modally.

The first general survey of Plate II shows that the general position and drift of the leucite rocks correspond well with the plotted areas of leucitic norms, $L^1O^1N^1$ to $L^9O^9N^9$. A very few fall outside and to the left of these limits, these rocks being without normative leucite, and some to the right of the area $L^9O^9N^9$, these being all normatively leucitic, but modally either leucitic or non-leucitic. The general direction of the axis of this area of the loci of leucitic rocks, or its drift, as it may be termed, is distinctly parallel to that of the inclination of the leucitic areas, especially to that of the lines *ON*.

Again, it will be observed that the abnormatively modal rocks (as regards leucite) lie for the most part toward the extreme right and left, while those which are normatively modal as regards the presence of leucite (represented by colored circles) occupy in general an intermediate position. Thus the rocks with leucite in the norm but not in the mode, and therefore abnormative in this respect, (represented by uncolored circles), are found, with few exceptions, well to the right or toward the low silica side of the diagram. On the other hand, the rocks with leucite in the mode but not in the norm (represented by colored squares) are almost all well toward the left or toward the side of high silica, and those free from either normative or modal leucite still more to the left.

A further fact which is to be noted is that none of the rocks with abnormatively modal leucite fall inside the quartz-orthoclase-albite area OAQ, in this conforming to the conclusion reached above, that leucite is not formed from magmas with an excess of silica or normative quartz.

Advancing more into details in our comparison, we must determine whether the rocks with leucite in the norm, or in the mode, or in both,

fall within the leucitic areas corresponding to their content in molecules of anorthite and femic minerals. This is the crucial test of the validity of our assumed order of affinity for silica; for it follows from the preceding discussion that for any given set of magmas containing a definite amount of anorthite and femic molecules in the norm (however these may be crystallized in the mode), but with varying amounts of silica and potash the loci of normatively leucitic rocks (which should also be modally leucitic) derived from them should fall within the corresponding leucitic area; and those free from normative leucite (which should also be free from this in the mode) should fall outside of this, either to the right or to the left.

We have seen that the introduction of salic lime into the magma causes only a slight change in the positions of the leucite-nephelite and orthoclase-nephelite boundaries of the leucitic area, though it has a much greater effect on the leucite-orthoclase boundary above, lowering this very decidedly. The effect of the introduction of the constituents of the femic minerals, on the other hand, is much more marked and varied in its character. The leucitic area shifts somewhat to the left if pyroxene enters into the norm,[1] while with olivine, and with magnetite and other minerals free from silica, the shift is still greater and toward the right or less siliceous end. At the same time, the upper boundary is lowered to an extent even greater than is caused by salic lime. It is to be remembered, however, that, whatever the constituents thus introduced or assumed to be present, the angle *LNO* and the inclination of the leucitic area to the horizontal line QAMN do not vary, the lines *LN* and *ON* always being parallel. A few simple cases have been plotted on Plate II, but it is obvious that, for purposes of adequate comparison of actual rocks with their theoretical leucitic areas, some means must be had of determining the true position of the leucitic area corresponding to any given rock, whatever be its composition and however complex it may be as regards its mode or norm. Fortunately this determination is not difficult, nor does it involve an inordinate amount of calculation.

The method consists, in brief, of the calculation of the locus (expressed in terms of the percentages of silica and of potash) of one

[1] This shift toward higher silica would be still greater if aegirite enters into the problem, as it not infrequently does.

or more definite points of the leucitic area desired, when its size and position on the diagram can be readily laid down, the parallelism of the various lines here coming into use, and its relations to the locus of the rock can be studied. For this purpose any two of the points *L*, *O*, or *N*, may be used, but for practical purposes the simplest determination is that of the point *N*, the locus of a mixture of nephelite with the amounts of normative anorthite and femic minerals corresponding to the rock. From this the directions of the points *L* and *O* may be readily determined.

The actual process is as follows: The norm of the rock having been calculated in the usual way, the total percentage of the normative anorthite and combined femic molecules, and the total amount of silica belonging to them, are estimated. The difference between their combined percentage 100 per cent. is then assumed to be nephelite, and the amount of silica belonging to this is calculated. The sum of these percentages of silica (those of normative anorthite, femic minerals, and of nephelite) is then reduced to molecular ratio by dividing by 60, and the result is the locus *N* of the leucitic area corresponding to the rocks on the abscissal line QANM. The leucite-nephelite and orthoclase-nephelite boundaries of this area are determined by drawing lines from *N* parallel to the other *LN* and *ON* lines of the diagram, the points *L* and *O* being readily determined by calculating the amount of potash or silica corresponding to a mixture of anorthite + femic molecules and either leucite or orthoclase, respectively, in the same proportions that were used in the case of nephelite.[1]

In actual practice, however, it was found that the determination of the points *L* and *O* was seldom necessary, and the comparison between the leucitic area and the locus of the rock was accomplished without defacing the plotted diagram and very quickly, after the point *N* had been determined, by means of a square sheet of stiff paper from which a triangle had been cut, whose lower angle *LNO* and inclination as regards the lower edge of the paper corresponded to those of the plotted leucitic areas in the diagram. By placing the sharp lower apex of this triangular opening at the determined point *N*,

[1] The locus of *N* for every rock, as thus calculated, is given in the list of analyses in the Appendix.

keeping the lower edges of the sheet and of the diagram parallel, it could easily be seen if the locus of the rock fell within or without its corresponding leucitic area.[1]

It should be said that, in any such study of the relations of rocks to their theoretical areas, the data will be, of course, strictly comparable only if the analytical figures are reduced to the same condition, by eliminating water and other nonessential ingredients and by recalculating the remainder to 100 per cent. To render our comparisons strictly accurate, this should have been done for all the analyses whose loci are shown on Plate II. But this would have involved a very considerable amount of work and the expenditure of much time, which the study did not seem to warrant, especially as it was found that the changes in position thus brought about were for the most part so small as to be negligible in the scale of the diagram here given, except in the case of some manifestly altered rocks, the greater number of which have been omitted.

On examination of the diagram in this way it was found that, making due allowance when necessary for rather large amounts of water, carbon dioxide, etc., the loci of all the rocks with normative leucite fell inside their respective leucitic areas, with two exceptions, Nos. 92 and 177, which fall to the right of the area. But the norms of these show the presence of kaliophilite, there being therefore an excess of potash, so that their position is quite in accordance with our assumptions. Of the rocks without normative leucite the loci fall outside of the leucitic areas, with the exception of Nos. 104, 105, and 106, orendites and a wyomingite of the Leucite Hills. But these also have an excess of alkalies, as shown by the presence of potassium metasilicate in the norm, so that, while they should fall to the left of the line *ON*, being free from normative leucite, the large amount of potash raises their loci so as to make them fall inside the leucitic area. It must also be borne in mind that the rocks free from normative leucite include the vast majority of all known rocks, only a few of which are plotted in the diagram, and concerning whose locus outside the leucitic area there can be no question. We may therefore consider the proposition as established, namely, that the

[1] A square sheet of thin, transparent celluloid, properly marked, would be better than the paper.

locus of a rock will fall inside or outside its corresponding leucitic area according as it does or does not show leucite in the norm.

It will be observed that the great majority of these rocks which show both normative and modal leucite are distinctly high in potash, for the most part containing over .050 mol. prop. of K_2O, and that silica and potash both tend to increase with decrease in the amount of femic molecules, the black and the green circles lying above and to the left, and the red ones to the right and below; also the range in silica is greater with increasing potash. A study of the list of analyses will show that, with the exception of a leucite-syenite of Magnet Cove and the missourite of the Highwood Mountains, all these rocks are effusive flows.

But there are a considerable number of cases which do not conform to our assumed order and which are to be regarded as constituting exceptions to the rule, and which therefore demand an explanation. These exceptions are of two kinds—namely, rocks with normative leucite, but free from it in the mode, though falling inside their leucitic areas; and rocks with leucite developed modally, though free from it normatively, and falling outside their leucitic areas. The loci of the first kind of these exceptions, indicated by uncolored circles, fall for the most part well toward the less siliceous end of the diagram, and most of these rocks are low in potash and belong to the salfemane class. The loci of the other kind of exceptions, indicated by colored squares, fall mostly well toward the more siliceous end, the rocks are often quite high in potash, and they are pretty well distributed among the persalane, dosalane, and salfemane classes.

The cases of the first kind are exceptional, and do not conform to the assumed order of affinity, because no leucite has crystallized, though it should be present according to our theory; while the cases of the second kind are exceptional in that albite has been formed rather than nephelite, and leucite rather than orthoclase, at least in part, in these soda having an apparently greater affinity for silica than has potash.

But before considering these exceptions it will be pertinent to the discussion to assume another order of affinity, and to calculate the norms and their loci on the basis that soda has a greater affinity for silica than potash has, or, expressed mineralogically, that albite

will form rather than nephelite, and leucite rather than orthoclase, in which respect the cases of the second kind are peculiar. For this purpose we need only consider the simplest case, that of a persalic and peralkalic magma, without excess of silica and with alumina equal to the total alkalies, as formerly.

It is clear that on this assumption the line representing purely feldspathic norms, composed only of orthoclase and albite, will be identical with that calculated on the previous assumption. It will be the line O^1A^1 on Plate II (p. 270). Also the line representing purely lenic norms, composed only of leucite and nephelite, will coincide with L^1N^1. Similarly, if the magmas are perpotassic (that is, quite free from soda), the upper limiting line will coincide with the previous one $L^1O^1Q^1$.

The divergence from the previous assumption will be expressed by the line representing norms composed only of albite and leucite, along which these are in equilibrium, so that magmas with less silica for any given percentage of potash will yield norms composed of albite, nephelite, and leucite, while those with more silica will yield norms composed of orthoclase, albite, and leucite. This is the dotted black line L^1A^1 of Plate II. The orthoclase-albite-leucite area $L^1O^1A^1$ is comparatively small, and with a range in silica only from that of albite to that of leucite, while the albite-leucite-nephelite area $L^1A^1N^1$ is much larger and with a range in silica from that of albite to that of nephelite.

On this assumption, therefore, we should expect to find very many more rocks with leucite than rocks with orthoclase, and orthoclase rocks should be relatively less abundant on this assumption than should leucite rocks be on the other. Also we could expect to find leucite rocks with silica percentages up to 68.70, and the range in silica of leucitic rocks should increase with decreasing potash. It need scarcely be pointed out that the facts of petrography are directly contrary to these deductions. Furthermore, not a single leucite rock falls within the area $L^1O^1A^1$,[1] and the position of the line L^1N^1, and the shape and position of the areas $L^1O^1A^1$ and $L^1A^1N^1$, are wholly discordant with the positions of the leucitic rocks as actually observed and plotted. Similar discordances would be observed were

[1] The apparent exception seen in the diagram will be discussed later.

the affinity of other oxides for silica, as lime, magnesia, or ferrous oxide, assumed to be greater than that of potash; but these need not be discussed here.

The general coincidence between fact and theory on the first assumption, and the grave discordance observed on the second, are clear proof that the former is in general the correct one, and that, while some exceptions do exist, in the vast majority of cases potash has a greater affinity for silica than soda has. Dismissing, therefore, any other assumption as to affinity for silica than the one with which we started, we may proceed to examine the exceptional cases mentioned above. These show clearly that our assumed order of affinity, while valid in most cases, is not a constant one, but that it can be superseded by other factors, into the character of which we have now to inquire.

Considering first the rocks with normative but not modal leucite, it is found that a large proportion of them are effusive rocks containing glass, their incomplete crystallization rendering their evidence inconclusive. It will be observed, however, that the great majority of these glassy rocks, while low in silica, are relatively high in alkalies, especially soda. The list of analyses shows that they are mostly nephelinites and nephelite-basalts in common parlance, all belonging to the lenic orders, and that most of them are dosodic. Their incomplete crystallization is in accord with this relatively alkalic character, as the researches of Lagorio and others show that such alkalic magmas are prone to undercooling and the formation of glass. From what we know of the order of crystallization which generally obtains in effusive rocks, and the usually late appearance of leucite, it is highly probable that leucite would have formed, in many cases at least, had the conditions permitted complete crystallization. We may therefore reasonably eliminate these from the list of exceptions on the presumption that, had they been holocrystalline, they would have been modally leucitic and hence not exceptional.

But again we find a very considerable number of perfectly holocrystalline rocks with normative but not modal leucite, represented by uncolored circles. These, it will be observed, are apt to fall toward the lower part of the diagram; that is, they are poor in potash: and they lie for the most part well toward the right; that is, they

are low in silica. Furthermore, the greater part of them contain large amounts of femic minerals, falling in salfemane and dofemane, with a few in dosalane, and none at all in persalane. Again, it will be observed that, with some exceptions, especially of melilite-basalts, they are all intrusive bodies, which have therefore solidified under conditions very different from those of the effusive flows, as are almost all of the rocks with both normative and modal leucite.

Of these exceptional rocks some contain very considerable amounts of biotite, as Nos. 109, 140, 159, 164, and 193. These rocks are all intrusive, and the conditions of solidification were such that the potash, in combination with magnesia and ferrous oxide, and in the presence of mineralizers, formed the complex biotite molecule, instead of leucite and olivine, as would have been the case under other circumstances. It may be noted, however, that in biotite the potash controls as much or more silica than it does in leucite, and thus conforms to the assumed order of affinity. Thus, if the molecule of biotite be written as $(K,H)_2O.(Al,Fe)_2O_3.2SiO_2+n[2(Mg,Fe)O.SiO_2]$, the ratio of SiO_2 to K_2O in the salic portion is that of leucite if K : H be 1 : 1, while it is that of orthoclase if it be 1 : 2, as is usually the case. Consequently, while the physico-chemical conditions have brought about the formation of the very complex mineral biotite instead of the more simple minerals leucite and olivine, the assumed order of affinity may be considered to hold good.

Others of these exceptions, as Nos. 73, 125, 127, and 178, are rocks which consist very largely of hornblende or augite, and the norms of which contain very small amounts of leucite, only from 1 to 3 per cent. In these cases the amount of potash present is relatively so small that a great affinity for silica might be readily masked or overcome by the mass action[1] of the complex molecules of the minerals which make up most of the rock, and which would incorporate the small amount of potash in their molecules.

Some other cases are of ijolites and urtites, rich in nephelite and aegirite or aegirite-augite, as Nos. 100, 101, 102, 103, 158, 170, and 171. The formation of the sodic pyroxene in these is conditioned by the excess of alkalies over alumina and the presence of ferric oxide, and as the soda in this controls twice as much silica as it does in nephe-

[1] Cf. S. L. Penfield, *American Journal of Science*, Vol. XXIII (1907), p. 25.

lite, relatively less is left for the potash. The latter enters into the modal nephelite, which, as we know, always contains considerable potash and apparently has a rather complex molecule. Nephelite is present in very large amounts in these rocks, so that its mass action, as well as that of the abundant and complex pyroxene (which often contains some potash), may reasonably be considered to come into play in capturing the potash and preventing the formation of leucite. It is highly probable, also, that the physical conditions enter in as factors, since the rocks just discussed are all intrusive, while we find some with very similar chemical characters (as Nos. 99, 162, and 163) which have solidified at or near the surface and which contain much modal leucite, in spite of their high content of soda.

There are also some melilite basalts (Nos. 146, 157, 179, 186, 187, 188, 194 ,and 195), in which glass is present either in very small amount or not at all, so that the absence of leucite from these effusive rocks cannot be ascribed to incomplete crystallization. This is to be attributed rather to the mass action of the abundant, complex melilite, which always contains some potash; to the comparative richness of these rocks in soda, and the consequent forcing of part of the potash into the abundant nephelite; and in some instances to conditions which favored the stability of biotite, as in the alnoäl types (alnöites).

Let us now examine the exceptions of the other sort, those with abnormative modal leucite. These are exceptional in that, although the magma contained sufficient silica to permit the entrance of all the potash into orthoclase, as an actual fact this constituent did not take all of its theoretical quota of silica, but was content with less, forming leucite in whole or in part.

Examining the norms of these rocks, it is found that, with a few exceptions to be discussed later, they are all deficient in silica, normative nephelite and olivine being present in every case. Therefore the silica liberated through the formation of leucite instead of orthoclase by the potash could form either albite from the normative nephelite, or pyroxene from the normative olivine, or both. We find, however, that olivine is present modally in nearly all these rocks, and that they contain almost constantly abundant albite, either in soda orthoclase,or in plagioclase, or in both of these. Furthermore,

my comparative study of the norms and modes of the Italian leucitic rocks[1] showed that it was more frequently the normative nephelite rather than the normative olivine which became silicated, though the latter may also take up silica. If follows then in these cases that, not only did the potash show a less affinity for silica than did the soda, at least in part, but that the soda had a greater affinity for silica than had the magnesia and ferrous oxide. This latter fact, it will be observed, is in perfect harmony with the order of affinity for silica assumed as fundamental in the calculation of the norm and mentioned above.

One more fact is to be noted in this connection—namely, that, while the amount of leucite formed varies much, even attaining the maximum possible in some cases, the silica liberated is never more than what may be completely used up in the formation of either albite or pyroxene, so that we never find an excess of it which would be crystallized as quartz. This is in accordance with the conclusion reached from the study of the diagrams, that quartz should not occur with leucite; and this applies as well to nephelite.

These exceptional cases, represented by colored squares, fall toward the left side of the diagram, extended over a rather broad oblique zone, which is approximately the space between the lines O^6N^6 and O^4N^4, only a few being to the right of this on the less siliceous side, while rather more fall to the left of O^4N^4. As regards potash they vary widely, from about .025 to .125. In connection with their distribution it must be remembered that, were all known rock analyses plotted, this space would also contain a much greater number of uncolored squares, representing rocks free from both normative and modal leucite, only a few of which are presented here.

This zone, occupied by rocks which are normatively free from leucite, but which may or may not carry it in the mode, is that of the magmas which have been referred to as "critical" ones, as regards the formation of leucite, this implying that they are in a nicely balanced condition chemically, so that a comparatively slight change in the

[1] *The Roman Comagmatic Region* (Carnegie Publication No. 57, 1906), pp. 155, 187. Cf. also A. Lacroix, *Comptes Rendus*, Vol. CXLI (1905), p. 1191, who shows that in some cases much of the olivine may take up silica, and so induce the formation of leucite, when the soda is so low that the entrance of all of it into albite may not do this.

physical conditions during solidification may induce or prevent the formation of leucite.

It has been noted above that the replacement of orthoclase by leucite may take place to varying degrees, and when the positions of these colored squares are compared with their respective leucitic areas, it is found that, as a general thing, the nearer they lie to these, the richer they are apt to be in leucite, and the more completely the potash has entered this mineral; while the farther away they are, the poorer the rock is in leucite. So that it may be said that the tendency to form leucite increases with the nearness of the locus of the rock to its leucitic area, or as silica and soda decrease and as potash increases, other things being the same.

Indeed, an examination of the published descriptions of the rocks which fall well to the left of and far from their leucitic areas reveals the fact that the amount of leucite in most of them is very small, and that this mineral is made prominent in the name chiefly because of its rarity, and of the desire to distinguish varieties containing it, even in small amounts, from similar rocks which are free from it. These cases would include such rocks as the leucite-banakites and shoshonites of the Yellowstone National Park, the leucite-kulaite of Phrygia, leucite-tephrites of Bohemia, and leucite-rhomben-porphyries of Kilimanjaro, and many others, into the details of which it is unnecessary to enter here.

But, even granted the accessory character of the leucite in these rocks, they still do not conform to our assumed order of affinity. There are also those rocks in which the abnormative leucite forms an essential and abundant component; and, furthermore, we have to take into consideration the fact that in the rocks with both normative and modal leucite the amount of the latter almost always exceeds that of the former, so that actually a greater amount of leucite has been formed than is demanded by theory.

In this connection it will be of interest to give a few illustrations of such relations of norm and mode, so as to show the extreme variations which are possible, and the actual divergencies in some cases. In the adjoining table are given the norms of some Italian leucitic rocks, in which the amount of modal leucite has been estimated. The columns headed "a" are calculated on the regular assump-

tion that potash, and those headed "b" on the assumption that soda, has the greater affinity for silica. The amount of leucite actually present in the rock is given in the legend below.

	I		II		III		IV	
	a	b	a	b	a	b	a	b
Or	52.26	27.52	50.04	26.69	61.72	10.56	11.20	none
Ab	17.29	28.82	15.20	26.20	0.52	24.63	none	11.00
An	8.62	8.62	12.23	12.23	9.45	9.45	13.07	13.07
Lc	none	19.40	none	18.31	none	40.11	26.60	35.32
Ne	6.25	none	5.94	none	13.06	none	12.78	6.84
Di	6.05	6.05	7.17	7.17	7.98	7.98	23.55	23.55
Ol	1.05	1.05	1.87	1.87	1.97	1.97	6.05	6.05
Mt	4.41	4.41	3.94	3.94	2.32	2.32	3.48	3.48
Il	1.06	1.06	1.37	1.37	1.52	1.52	0.76	0.76
Hm	0.80	0.80	.....	.....	.....	.....	.....	.....
Ap	0.94	0.94	0.53	0.53	0.34	0.34	1.77	1.77

I. Bagnoreal ciminose (leucite-trachyte). Bagnorea, Vulsinian District (*Rom. Com. Reg.*, p. 68). Modal leucite = 8.8 per cent.

II. Bagnoreal ciminose (leucite-trachyte). Monte Venere, Ciminian District (*Rom. Com. Reg.*, p. 69). Modal leucite = 16.9 per cent.

III. Foglianal vicose (leucite-tephrite). Monte Fogliano, Ciminian District (*Rom. Com. Reg.*, p. 93). Modal leucite = 40.6 per cent.

IV. Scalal braccianose (leucite-tephrite). La Scala, Mount Vesuvius (*Rom. Com. Reg.*, p. 120). Modal leucite = 35.6 per cent.

On comparison of the norms and modes it will be seen that in I only about half the maximum possible amount of leucite has developed, in II the maximum is nearly reached, and in III and IV the whole amount of the potash possible has gone into leucite, no orthoclase being present in the mode of the last rock.[1]

It is evident that the problem is fundamentally different from that presented by the former sort of exceptions, where the absence of leucite could be readily and reasonably explained either by incomplete crystallization or by the mass action of the abundant and complex alferric minerals and nephelite. Here, on the contrary, the majority of these abnormatively leucitic rocks contain relatively large amounts

[1] A similar comparison has been undertaken by Lacroix (*Comptes rendues*, Vol. CXLI [1905], p. 1190), in discussing the granular leucitic sommaites of Monte Somma, though his norms are not calculated in the regular way, as he makes all the soda enter albite and does not assume the normative diopside molecule with $CaSiO_3$=(Mg, Fe) SiO_3.

of potash and small amounts of alferric minerals and often of nephelite, so that the mass action of these (which would also certainly tend to prevent the formation of leucite) may be neglected. Furthermore, some of these abnormatively leucitic rocks are vitreous, so that the leucite has been formed in spite of their incomplete crystallization.

The explanation of the abnormality in the behavior of potash toward silica in these cases may be explained by two sets of factors, or rather by a combination of the two.

The tendency of the $CaAl_2Si_2O_8$ molecule to crystallize with that of $NaAlSi_3O_8$ as the mixed crystals of the soda-lime feldspars is well known. Pure anorthite is a rather rare feldspar, being met with, for the most part, only in rocks belonging to docalcic and percalcic rangs, gabbros and some basalts, though it occurs in a few rocks, andesites, vulsinites,and ciminites, which are decidedly alkalic. But, speaking generally, the affinity of lime (in anorthite) for soda (in albite) seems to be very strong. Likewise purely potassic orthoclase and microcline are rarely met with, these minerals nearly always carrying very notable amounts of soda, as may be seen in the analyses given in Hintze's *Mineralogie.* On the other hand, both albite and anorthite, as well as their mixed crystals, the soda-lime feldspars, contain very little potash, the amount of this constituent in the analysis of the soda-lime feldspars being usually very small, and generally far less than the amounts of soda in orthoclase and microcline.

It is reasonable, therefore, to suppose that, under certain conditions, the affinity of lime and potash for soda to form feldspars may supersede the usually superior affinity of potash for silica, with the result that the $CaAl_2Si_2O_8$ molecules in the magma, and to a less extent those of $KAlSi_3O_8$, will capture a certain amount of the soda present, forming soda-lime feldspar and soda-orthoclase. This soda will therefore bind three times as much silica as it would do if it entered into nephelite, leaving a correspondingly less quantity of this available for the potash, which would necessarily form leucite, if the amount of silica left available for it were less than enough to form only orthoclase.

Confining our attention for the moment to the soda-lime feldspars, it is evident that, on this hypothesis of the superior affinity of lime for soda, the abnormative formation of leucite would be aided by

the actual withdrawal of the amount of silica entering the albite molecule from the possibility of chemical combination with potash, that is, by the early crystallization of the sodic feldspars, at least in great part, thus bringing about the formation of leucite at a later stage. Such a withdrawal of silica by soda is rendered possible by the fact that labradorite has a greater tendency toward crystallization than have orthoclase and leucite,[1] as shown by the general truth of Rosenbusch's order of crystallization as far as regards labradorite, orthoclase, and leucite, which immediately concern us. Specific instances of this are presented by the Italian lavas, in the mantles of orthoclase about cores of anorthite and labradorite,[2] which have also been observed elsewhere, and in the inclusions of labradorite in large leucite phenocrysts.[3]

The objection may be raised to this explanation that the more calcic members of the soda-lime feldspar series, those with more anorthite than Ab_1An_1, contain less silica than does leucite, and that, furthermore, it is precisely these more calcic members, especially labradorite, which are most apt to occur in connection with leucite, as is shown in the case of the Italian leucitic rocks. It might therefore seem to follow that the early crystallization of labradorite (Ab_1An_2), with a silica percentage of only 51.4 less than that of either leucite or orthoclase, would bring about in the remaining portion of the magma an increase of the silica percentage relative to that of potash, so that the early separation of labradorite ought to tend to prevent, rather than induce, the crystallization of leucite. Such an objection, however, leaves out of account the relations of the soda to the silica, and overlooks the fact that in entering albite molecules at an early stage of the crystallization it binds more silica than it would do if it were not thus removed and crystallized later as nephelite.

From the usually late crystallization of the alkali-feldspars it

[1] Cf. C. Doelter, *Petrogenesis* (1906), p. 136.

[2] H. S. Washington, *Journal of Geology*, Vol. IV (1896), p. 549; *The Roman Comagmatic Region* (1906), p. 30.

[3] H. S. Washington, *The Roman Comagmatic Region* (1906), pp. 34, 91. Cf. E. Hussak, *Neues Jahrbuch* (1890), Vol. I, p. 168. It may be mentioned that labradorite is not listed as an inclusion in leucite by either Rosenbusch (*Mikroskopische Physiographie*, Vol. I, second half [1905], p. 32) or Iddings (*Rock Minerals* [1906], p. 242).

would seem that the influence of the binding of silica by soda in the formation of soda-orthoclase would be felt chiefly in peralkalic rocks, or, in more calcic ones, after the formation of labradorite had ceased, at least in great part. In the latter case its influence is probably comparatively slight, though in peralkalic rocks the crystallization of the alkali-feldspar and leucite is apt to be partially synchronous, so that it would be felt more strongly in these and would very materially tend to favor the formation of leucite.

In the preceding explanation it has been assumed to be a case of relative affinities, that of potash for silica and of lime and potash for soda. But it is clear that such questions of affinity may be disregarded and the result considered merely as dependent on the relative tendency toward crystallization of the several minerals involved, especially labradorite (or other soda-lime feldspars), orthoclase, and leucite. The effect would be the same in either case in influencing the formation of leucite.

Another mineral which may enter into the problem, and which would strongly influence the formation of leucite in certain cases, is analcite. This contains twice as much silica as does nephelite, and its crystallization would abstract silica from the magma, analogously to the crystallization of albite, though not to the same extent. Analcite contains two molecules of water, so that its formation can take place only when the molten magma contains water and under peculiar physical conditions. But that its presence may explain the formation of abnormative leucite in some rocks has been clearly shown by Pirsson.[1]

The presence of alferric minerals has been disregarded as yet, since the amount of these in the exceptional rocks now under consideration is usually not very large. But a slight consideration of their characters and the relations of norm and mode will show that the influence of the early crystallization of these is also favorable to the development of leucite by abstracting from the magma an abnormative amount of silica. Considering augite alone, which is the alferric mineral most commonly met with in connection with leucite, the study of the relations of the norms and modes, as in the Italian

[1] L. V. Pirsson, *Bulletin No.* 237, U. S. Geological Survey (1905), pp. 11, 170.

rocks, shows that it is largely composed of the normative diopside. With this there enters also a smaller amount of the normative anorthite to furnish the alumina, and of normative magnetite to furnish the ferric oxide, both of which are present in the augite. To satisfy the demands of the normal augite formula, which may be stated as $m\mathrm{Ca(Mg,Fe)Si_2O_6}+n\mathrm{(Mg,Fe)(Al,Fe)_2SiO_6}$, ferrous oxide and magnesia must be supplied from normative olivine, which will take up as much silica again as it contains to form a metasilicate molecule. The ferrous oxide of the normative magnetite will also demand its equivalent of silica to conform to the augite formula. Such, at least, was the set of readjustments which were found to be demanded in the case of the Italian volcanic rocks, the augite of which had been analyzed, and it is probable that the same or a very similar set would hold good in others. It will be seen that these readjustments are in the direction of the abstraction of silica from the magma by the early crystallization of augite, so that, while they may be slight in these rocks which are persalanes or dosalanes, yet the tendency of the crystallization of augite from a magma would be to favor the later formation of leucite. The influence of the early crystallization of either hornblende or biotite would be quite analogous; but, as they seldom occur in connection with leucite, they need not be discussed.

Examining the modes of the abnormatively leucitic rocks plotted on Plate II, it will be found that the great majority of them (belonging to domalkalic or alkalicalcic rangs) carry considerable soda-lime feldspar, much of which has crystallized prior to the leucite, so far as may be gathered from the published descriptions, and as may be inferred from the usual order of crystallization. The sodic character of the alkali-feldspar is less easily demonstrable in most cases, but in the Italian rocks studied by me it was shown to be invariably decidedly sodic, ranging from Or_3Ab_1 to Or_1Ab_2 in the modally leucitic rocks, the composition in most cases being about Or_1Ab_1, and from Or_6Ab_1 to Or_8Ab_9 in those free from leucite, the average composition being about Or_2Ab_1. The more highly sodic character of the alkali-feldspars in the modally leucitic rocks is thus quite marked. This is perhaps best seen in the case of two arsal monzonoses. That from Poggio Cavaliere contains no modal leucite, and its alkali-feldspar has the composition Or_5Ab_1; while that of L'Arso contains

about 2 per cent. of leucite, and its alkali-feldspar is Or_4Ab_3; both rocks being chemically closely alike.[1]

It should, of course, be possible to test this theoretical withdrawal of silica by the crystallization of soda-lime feldspar and soda-orthoclase by calculation based on the modes of actual rocks. The data necessary for this would be an exact knowledge of the order of crystallization, both qualitatively and quantitatively, and the compositions of the several modal minerals. It is clear that the former would be practically almost unattainable, owing to the difficulty of deciding the relative periods in many cases, and especially on account of the simultaneous crystallization of many of the minerals.

An attempt was made, however, on several of the Italian leucitic rocks, the modes of which have been quite exactly estimated. It was assumed that all the femic and alferric minerals, the ores, augite, and olivine, as well as all the soda-lime feldspar, had crystallized before that of the soda-orthoclase, leucite, and nephelite had begun. This, of course, may or may not be in accordance with the facts, but no definite, quantitative estimate of the relations was possible in any case. Unfortunately the composition of the alkali-feldspar was also unknown, and would have been almost impossible to determine in any case, as an analysis of the orthoclase phenocrysts would not necessarily indicate that of the more numerous groundmass feldspar laths, which cannot be separated mechanically and satisfactorily from the other constituents, owing to their small size and intimate juxtaposition.

Even though, on this basis, the calculations resolved themselves largely into working out backward the norm from the estimated mode, yet the fact that the amounts of some of the minerals, especially the leucite, had been estimated physically, and the composition of the soda-lime feldspar had been determined optically, gives them some weight. It would take up too much space to give the details here, but it may be stated that the results were fully confirmatory of the view that the early crystallization of soda-lime feldspars and of soda-

[1] *The Roman Comagmatic Region* (1906), pp. 75, 77. The determination of the composition of the Arso feldspar here, based partly on Rosiwal estimates of the amounts of leucite, augite, and olivine, and partly by readjustments of the other constituents, agrees well with that determined chemically by Fuchs (*T. M. P. M.* [1872], p. 233), who gives figures yielding $Or_{10}Ab_7$. The Poggio Cavaliere feldspar has not yet been analyzed.

orthoclase diminish the silica in the magma relatively to potash, and hence favor the crystallization of leucite. This was found to be true of soda-lime feldspar alone, as the portion of the magma remaining after the abstraction of the constituents of the minerals mentioned above, and neglecting the presence of albite in the alkali-feldspar, always yielded a greater amount of normative nephelite than that shown by the rock, thus proving that silica had been abstracted. And, naturally, the effect was still more marked if soda was assumed to go into the alkali-feldspar prior to the crystallization of leucite, the amount of this calculated from the composition of the last portion of the magma being the same as that determined in the mode, even if none is present in the norm, of the rock.

It will be observed that this favorable influence of the crystallization of soda-lime feldspars on the formation of leucite, consequent on the presence of considerable salic lime in the magma, is apparently at variance with the theoretical conclusion reached previously (p. 277), and based on the relative sizes of the leucitic areas, that the presence of anorthite should tend to lessen the probability of the presence of leucite. But it must be remembered that this was based only on a consideration of ideal norms, and that the influence of anorthite in forcing the soda to take up extra silica to form the modal albite molecule was disregarded.

It may also be pointed out that this action of the anorthite molecule offers a satisfactory explanation of the fact, noted by Zirkel and mentioned above (p. 258), that leucite is more often found in combination with plagioclase than with orthoclase.

On this assumption, the tendency to the formation of abnormative leucite will increase with the potash content of the magma, since the ratio of potash to silica will increase in the last portions to crystallize, and also, especially when potash is not very high, with its richness in salic lime and in soda, since the chemical composition will then be favorable to the formation of soda-lime feldspars. In conformity with these conclusions we have already noted the fact that the loci of these abnormative rocks are apt to fall rather near their respective leucitic areas, and that they are apt to contain the more leucite the nearer they approach these—that is, the higher they are in potash. It will also be noted that those rocks in which abnorma-

tive leucite is an accessory are quite calcic, belonging to the second and third rangs.

The influence of this factor just discussed is also seen in those rocks which carry both normative and modal leucite. In all of these, with one exception, where the mode has been adequately estimated, as in the Italian lavas, the amount of modal leucite surpasses that in the norm, so that a considerable portion of it is really abnormative. The exception is the missourite,[1] in which the amount of modal leucite is less than that in the norm, the difference being attributable to the formation of some biotite under the intrusive conditions.

On a previous page (371) it was suggested that the supersession of the affinity of lime and potash for soda over that of potash for silica could take place "under certain conditions." An idea of what these conditions may be is furnished by the long-recognized fact that leucite is characteristically a mineral of effusive igneous rocks. That it sometimes occurs in intrusive bodies is now well established by occurrences in Montana, Arkansas, and Brazil. It may be noted, as bearing on the problem, that there is only one known intrusive rock, missourite, in which purely potassic and unaltered leucite is found. In the others, as the fergusite and leucite-shonkinite of Montana,[2] and the leucite-syenites and leucite-tinguaites of Brazil and Arkansas, the "leucites" are really pseudo-leucite, a mixture of alkali-feldspars and nephelite.[3]

But such occurrences of leucite are quite exceptional, and the generally recognized law may still be considered to hold good, that conditions which control during the solidification of effusive rocks favor the formation of leucite, while those obtaining in intrusive bodies tend to prevent it, the chemical composition of the magma admitting of the readjustments of silica necessary for the formation of leucite.

In this connection a few analyses will be worth quoting, which show these relations clearly. Others might be added,[4] but those

[1] L. V. Pirsson, *Bulletin No. 237*, U. S. Geological Survey (1905), pp. 118, 119.

[2] L. V. Pirsson, *op. cit.*, pp. 106, 84.

[3] Cf. Rosenbusch, *Mikroskopische Physiographie*, Vol. II, first half (1907), pp. 196, 617.

[4] A similar comparison of analyses of leucitic and non-leucitic rocks of almost identical chemical composition is given by Lacroix (*Comptes Rendus*, Vol. CXLI [1905], p. 1190).

given below demonstrate how, of two magmas of practically identical chemical composition, the one which solidifies under intrusive conditions will be free from leucite, the potash going only into orthoclase in conformity with the norm, while in effusive flows leucite is apt to be formed, the amount of orthoclase shown in the norm being diminished modally and replaced by leucite, while the amount of normative albite is increased modally. Only the amounts of the more important constituents are given here.

	I	II	III	IV	V	VI	VII
SiO_2	55.38	55.87	54.55	54.20	48.98	49.59	47.98
Al_2O_3	23.74	20.85	19.07	19.38	12.29	14.51	13.34
Fe_2O_3	0.63	2.34	2.41	3.83	2.88	3.51	4.09
FeO	1.26	1.10	3.12	2.14	5.77	5.53	4.24
MgO	0.81	0.48	1.98	1.35	9.19	6.17	7.01
CaO	0.67	3.07	3.15	2.15	9.65	9.04	9.32
Na_2O	5.29	4.81	7.67	8.01	2.22	3.52	3.51
K_2O	10.05	10.49	4.84	5.28	4.96	5.60	5.00

I. Grano-beemerose (nephelite-syenite). East Cape, Siberia. Washington, *American Journal of Science*, Vol. XIII (1902), p. 176.

II. Sabatinal beemerose (leucite-phonolite). Lake Bracciano, Italy. Washington, *Roman Comagmatic Region* (1906), p. 47.

III. Grano-laurdalose (laurdalite). Laugendal, Norway. Brögger, *Eruptivgesteine des Kristianiagebietes*, Vol. III (1899), p. 19.

IV. Phyro-laurdalose (leucite-rhombenporphyry). Kilimanjaro, East Africa, Finckh, *Rosenbusch Festschrift* (1906), p. 392.

V. Grano-shonkinose (shonkinite). Yogo Peak, Little Belt Mountains, Montana. Weied and Pirsson, *American Journal of Science*, Vol. L (1895), p. 474.

VI. Leucite-shonkinose (leucite-shonkinite). East Peak, Highwood Mountains, Montana. Pirsson, *Bulletin No. 237*, U. S. Geological Survey (1905), p. 108.

VII. Leucite-phyro-shonkinose (analcite-leucite-basalt). Highwood Peak. Highwood Mountains, Montana. Pirsson, *op. cit.* p. 168.

It may be thought that the slight differences observable in some of the constituents, especially in silica and potash, may account for the differences in the modes, at least in part. But study of the norms and the modes, so far as these latter are exactly ascertainable from the descriptions, shows indubitably that these chemical differences are entirely too slight to bring about the very great divergencies between the modes of the several pairs of rocks. The amounts of orthoclase and nephelite in the one, and of leucite and albite in the other member,

are entirely too great to be caused only by the slight variations in silica, soda, or potash shown by the analyses given above. In such magmas, therefore, whether leucite is formed or not must be held to depend upon some factor or factors extraneous to the magma itself; and these are to be looked for in the physical conditions which obtain during the solidification.

These conditions have been discussed by many petrographers, and it seems unnecessary to enlarge on them here, in view of the fact that the attitude of this paper is dominantly chemical, and because of the inadequacy of our knowledge of the physico-chemical properties of leucite, and other minerals, mentioned at the beginning of this paper (p. 259). It must suffice to say that the chief physico-chemical factors which under effusive conditions induce the formation of leucite in magmas chemically capable of permitting it seem to the writer to be:

a) The great tendency toward crystallization of the more calcic soda-lime feldspars and of leucite, that of nephelite being also considerable, but that of orthoclase being very slight under such conditions.

b) The relative stability of orthoclase, soda-lime feldspars, leucite, and nephelite, at different temperatures and pressures, the stability of the second and third of these being apparently greater under effusive conditions than those of the first and fourth. This is a matter which demands thorough experimental investigation.

c) The absence of mineralizers under effusive, and their presence under intrusive, conditions; the former permitting the magma to solidify and crystallize at a higher temperature, and so favor the formation of leucite, while the latter diminishes the viscosity, and thus permits the crystallization to proceed at a lower temperature and in a more fluid medium, which would favor the formation of orthoclase.

d) It is possible that, whether a molten magma is at rest or in motion, or whether it is subject or not to shocks, as of explosions of steam in a volcanic vent, may be of importance in inducing the crystallization of some minerals such as leucite; since it is known that tapping or agitation will frequently bring about the crystallization of an undercooled liquid.

The influence of other factors might be adduced, but the above must suffice. In any case, an appeal to them in explanation of the

formation of any mineral in igneous rocks must partake more or less of the nature of begging the question, in the absence of properly controlled physico-chemical experimental data. Any conclusions based on our present knowledge of the physico-chemical relations of minerals must rest on very insecure bases, and it were better not to attempt to draw them.

A few words may be devoted to the subsidiary point of the relative abundance of leucitic rocks. We have seen above (p. 271) that the size of the leucitic area is much smaller than those of the non-leucitic ones, the relations varying with the content in anorthite and femic molecules, but with a maximum of 21.61 per cent. of the whole in peralkalic and persalic magmas. It follows from this that the number of leucitic rocks actually to be observed should be considerably

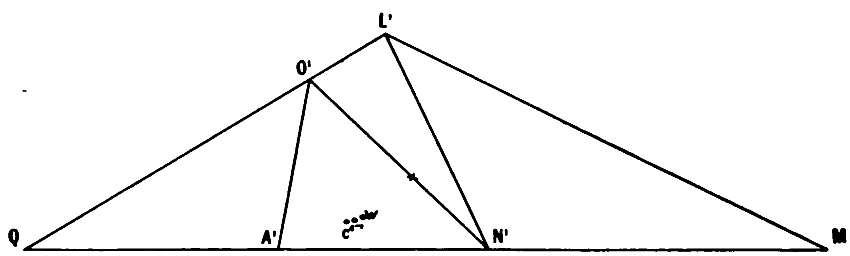


FIG. 1

less than the non-leucitic ones, though it does not follow that the actual relations must be exactly the theoretical ones. This would depend upon the general and the average compositions of all igneous rocks and the correspondence of these with the theoretical area *QLM*. As a matter of fact, we find that these do not correspond, the center of gravity of *QLM* falling at the point X (on the line O^1N^1), and the locus of the average rock well to the left of and below this, as shown in the adjoining figure. That is, igneous rocks, as they actually occur, are higher in silica and lower in potash than our theoretical magmas, of which amounts proportional to the theoretical limits of each are represented in our diagrams. It follows from this that leucitic rocks should actually be much more rarely met with than is indicated by the relative sizes of the various theoretical areas. That this is actually the case is shown by the following figures.

The normatively or modally leucitic rocks plotted in the diagram are distributed thus:

Those with normative and modal leucite	40
Those with normative but not modal leucite (vitreous)	21
Those with normative but not modal leucite (holocrystalline)	29
Those with modal but abnormative leucite	43

Reckoning the vitreous rocks with the first group, it will be seen that those which do not contain leucite when they should, and those which do contain it when they should not, pretty nearly balance each other, though the former are somewhat in the minority. They correspond, however, sufficiently well to allow the assumption for our purpose that the actual number of modally leucitic rocks corresponds with the number of those which should be leucitic according to our theory.

Now, taking the number of analyses to represent the relative amounts of the various kinds of igneous rocks, which is admittedly not strictly accurate, but sufficiently so for our purpose, and in any case being the only statistical basis we have, we find that all the analyses of igneous rocks to be found in Roth's *Tabellen* and in my *Collection*, as well as in the analyses published since and collected by me, number altogether 6,333. Of these, 278 are called leucitic, that is 4.41 per cent., while 6,055, or 95.59 per cent. are non-leucitic. While these figures are not of very great significance, on account of the unsatisfactory character of the data on which they are based, yet they are of some interest, and, taking into account the general characters and the average of igneous rocks, which would tend to lower very much the relative amounts of leucitic rocks, they are quite in harmony with our theory.

We may briefly summarize our comparison of the actual and the theoretical occurrence of leucite as follows:

The vast majority of igneous rocks conform to theory, based on the superior affinity of potash for silica, in that those whose norms are free from leucite are for the most part free from modal leucite, and the loci of nearly all of them fall outside their respective leucitic areas; while those whose norms are leucitic are very commonly modally leucitic also, and their loci all fall within their leucitic areas.

As regards modal leucite, there are certain exceptions which,

while not very numerous, are yet significant, and which may be referred to two kinds: those which are modally free from leucite, though they contain it in the norm, the abnormality being explicable, in part by the incomplete crystallization, and in part by the mass effect of the complex minerals present in abundance in these rocks, and their comparative paucity in potash; and those whose modes contain abnormative leucite, either showing none of this in the norm, or containing modally more than exists normatively, these cases being explicable by the early crystallization of soda-lime feldspars (due either to the superior affinity of lime for soda or to the great tendency toward crystallization of these feldspars), and of soda-orthoclase or analcite which may crystallize either prior to or at the same time as the leucite.

In both classes of exceptions the conditions of solidification seem to have a determining effect, those obtaining in effusive rocks favoring, and those in intrusive rocks deterring, the formation of leucite.

A few exceptions, which cannot be explained by any of the suppositions made above, remain to be discussed. The first is the so-called leucite-granite-porphyry of Brazil, described by Hussak,[1] which consists of large phenocrysts of pseudo-leucite in a fine-grained groundmass composed of orthoclase and quartz, thus apparently forming an exception to the otherwise invariable incompatibility of quartz and leucite. This highly anomalous occurrence is explained by Hussak (*loc. cit., p.* 26)as the result of a "granophyric" magma breaking through a leucite-foyaite or leucite-tinguaite; and this explanation may reasonably be accepted as the true one.

The only other exceptions which need be discussed are the wyomingite and the orendites of the Leucite Hills (Nos. 104, 105, 106), which carry abundant modal leucite and whose loci fall within their leucitic area, though they do not show either leucite or nephelite in the norm, and even in one case have normative quartz. These rocks, furthermore, have an excess of alkalies over that needed for feldspar and acmite, resulting in the presence of sodium and potassium metasilicates in the norm. The peculiar features of these rocks have been discussed by Cross,[2] who shows that they cannot be due to errors of analysis,

[1] E. Hussak, *Neues Jahrbuch* (1900), Vol. I, p. 22.

[2] W. Cross, *American Journal of Science*, Vol. IV (1897), pp. 131–34.

and who leaves the discordance between their chemical and modal characters unexplained. In this condition we also are perforce compelled to leave them still, as study of the relations of norm and mode, and consideration of the presence of the phlogopite, but add to the difficulties of explanation. These rocks may well be considered as, chemically, the most remarkable and the least susceptible of correlation of any igneous rocks so far discovered.

GENERAL CONCLUSIONS

From the above discussions and comparisons we may draw certain general conclusions, both as to the affinity of the various bases in igneous rocks for silica and as to the formation of leucite, these conclusions being stated under the two separate heads.

Affinity for silica.—The assumption with which we started, that potash has a greater affinity for silica than has any of the other oxides, is amply substantiated, and may be considered as fully established, subject to certain modifications mentioned later.

Next to potash, soda has the most affinity for silica, the affinities of magnesia and ferrous oxide being considerably less, so that normative nephelite will take up silica before normative olivine.

While these relative affinities apply in the great majority of cases, and under most conditions, yet, in accordance with the general laws of chemical affinity and of mass action, they are susceptible of notable change under certain conditions, especially of temperature and pressure, and the presence of mineralizers, and may be in part superseded by the influence of the mass action of abundant complex molecules and the relative crystallizability of the minerals involved, the influence of the ready crystallization of soda-lime feldspars constituting the most notable case in point.

Soda and lime, as alumino-silicates, have a strong affinity for each other, as have soda and potash alumino-silicates, though to a somewhat less extent; and if lime and soda are present in sufficient amount in the magma, these affinities may supersede, at least partially, the usual greater affinity of potash for silica.

In the presence of water in the magma, and under certain conditions, the affinity of soda for silica may supersede that of potash, resulting in the formation of analcite and leucite.

These affinities must be regarded as acting in one direction only, that mentioned in the several cases above, since, were they reversed, the resulting modes would be quite incompatible in general with our observations.

Formation of leucite.—The formation of leucite is an unusual occurrence, and the number of leucitic rocks will always remain but a very small fraction of all known igneous rocks.

The formation of leucite is, in general, primarily dependent upon the chemical composition of the magma, subject, however, to the modifying influence of certain factors, such as physical conditions and the mass action of complex mineral molecules, to be mentioned later.

The chief chemical factors involved are the percentages of silica and of potash, and the ratio of soda to potash, but this last and the amounts of the other constituents are of subordinate importance. These statements are subject to the modifications mentioned in the preceding paragraph.

Leucite will not be formed in rocks with an excess of silica—that is, more than enough to saturate the bases completely and form the most highly silicated mineral molecules possible. It follows from this that leucite and quartz are incompatible and will not occur together.

As regards silica, rocks containing leucite may range between the silica percentage of orthoclase (64.75) as a maximum, down to the absence of silica as a minimum limiting value. The actual possible maximum will, however, depend upon the amount of anorthite and of femic molecules, all of these decreasing very markedly the possible amount of silica.

As regards potash, the limits lie between the percentage of leucite (21.56) as a maximum (though this may be conceivably exceeded owing to the existence of the kaliophilite molecule) and the disappearance of potash as a minimum. The actual maximum will depend upon the amounts of anorthite and of femic molecules present, as in the preceding case.

The greatest range in silica consistent with the formation of leucite, and consequently the greatest probability of its formation, for any given percentage of anorthite and femic molecules, will be found when the

percentage of potash is that of a mixture of orthoclase with the given amount of the other constituents mentioned. From this most favorable maximum the range in silica, and consequently the probability of the formation of leucite, will diminish rather slowly with decreasing potash, while, at the same time, the probability of the rock being non-leucitic, as well as the possible number of rocks, will increase. On the other hand, only leucitic rocks can be expected with higher potash than this amount, but their range in silica and the probability of their occurrence will diminish rapidly with increasing potash.

Similarly, the greatest range in potash, and hence the greatest probability of the formation of leucite, will be found when the silica percentage is that of a mixture of leucite with the given amount of anorthite and femic molecules. From this most favorable maximum, the range in potash and the probability of the formation of leucite will diminish slowly as silica decreases, but more rapidly as silica increases.

While the maximum ranges of silica and of potash, expressed in percentages of the whole rock are about the same (for example, 12.54 and 12.00 respectively in peralkalic persalanes), yet relatively to the amounts of each present the possible range of potash is much greater than that of silica. So that we may expect to find the potash range of leucitic rocks very great, while that of silica will be comparatively small.

If leucite is present in the norm of a rock, it should also be present in the mode, provided that the crystallization is complete and the magma has solidified under effusive conditions. The formation of leucite in such normatively leucitic magmas may, however, be, and often is, wholly prevented by the presence of femic constituents in large amounts, giving rise to the modal presence of alferric minerals with highly complex constituents, such as biotite, hornblende, augite, or melilite, the potash being incorporated in these by their mass action. The presence of abundant soda may also prevent the formation of leucite by the incorporation of the potash in the complex nephelite molecule. Both of these effects are most apt to occur if the rock has solidified under intrusive conditions. Leucite should therefore be rarely met with in highly femic rocks, as the dofemanes and perfemanes, as well as in those which are highly sodic, both of these characters implying, of course, that the magma is not very potassic.

If leucite is not present in the norm, we should not expect to find it in the mode, especially if the rock is intrusive. But if the magma has solidified under effusive conditions, is rather low in silica and high in potash, and if it contains considerable salic lime and soda, leucite is apt to form. The crystallization of soda-lime feldspar, and less often of soda-orthoclase or analcite, is a prerequisite to the formation of leucite in such cases, and the tendency to its formation will be the greater the higher the rock is in potash, though the presence of considerable salic lime and soda may bring about the crystallization of leucite even if the amount of potash is small. It follows from this that soda-lime feldspars will be frequent concomitants of leucite; and this we find to be actually the case.

The presence in the norm of such mineral molecules as nephelite or olivine, which are not fully silicated, is a necessary condition for the formation of modal leucite, if there is none in the norm; that is, the magma must be deficient in silica. Of these minerals, nephelite is the most important, modal leucite being usually formed by a readjustment of silica involving the taking-up of silica by normative nephelite to form modal albite, which usually enters the soda-lime feldspars. Olivine is much less prone to take silica away from potash, but may do so. The crystallization of alferric minerals, especially augite, also favors the formation of leucite by abstracting silica from the magma.

Effusive conditions tend to favor, and intrusive conditions tend to check or wholly prevent, the formation of leucite in magmas from which it is chemically possible for it to form. It is because of this that augite occurs more often with leucite than do hornblende or biotite. In general, the leucitoid mineral formed under intrusive conditions is the so-called pseudo-leucite, which contains a very considerable amount of soda, and which consists of an intimate mixture of orthoclase and nephelite.

Miscellaneous conclusions.—The preceding discussions emphasize the possibility of the formation of widely diverse modes from chemically identical magmas, these divergencies of the mode from the norm or from each other taking place in different directions and to varying degrees, from practically complete agreement with the norm to the greatest possible divergence from it, though these last are less

common than cases where the norm and mode correspond in many particulars.

The readjustments shown to be possible in the case of the leucitic rocks indicate that the mineral molecules probably do not exist as such in the molten magma, but that they are dissociated into simpler molecular groupings, or their constituent oxides or ions, capable of reacting differently among themselves according to the conditions of solidification.

The facts brought out in the preceding discussion do not seem to favor the theory of eutectic mixtures in explaining the crystallization of rocks, at least so far as the leucitic rocks are concerned.

There is indicated the possibility that pseudo-leucite is not a pseudomorph after original leucite, but that it replaces a distinct, soda-potash mineral, as yet unknown, which was not stable under the conditions following its period of crystallization. The evidence in regard to this will be discussed subsequently, in connection with some Sardinian leucitic lavas.

APPENDIX II

List of Rocks Plotted

No.	Symbol	SiO_2	K_2O	N	Norm and Mode	Name	Locality	Reference	Remarks
1	I.5.1.3	1.031	.071	.681	NoMo	Trachyte	Ischia	R.C.R. 20	Effusive
2	I.5.1.3	.997	.076	.673	NoMo	Trachyte	Mte. Cuma	R.C.R. 23	Effusive
3	I.5.1.3	1.006	.078	.696	NoMo	Trachyte	Mte. Nuovo	R.C.R. 23	Effusive
4	I.5.1.3	.987	.097	.672	NoMo	Trachyte	Mte. Vico	R.C.R. 23	Effusive
5	I.5.1.3	1.027	.081	.678	NoMo	Trachyte-obsidian	Ischia	R.C.R. 28	Effusive
6	I.5.2.2	.968	.095	.674	NoMo	Vulsinite	Bolsena	R.C.R. 31	Effusive
7	I.5.2.2	.960	.093	.675	NoMo	Vulsinite	Astroni	R.C.R. 31	Effusive
8	I.5.2.2	.958	.089	.671	NoMo	Vulsinite	Astroni	R.C.R 31	Effusive
9	I.5.2.2	.936	.112	.674	NoMl	Leucite-trachyte	Mte. Vico	R.C.R 36	Effusive
10	I.5.2.2	.920	.102	.665	NoMl	Leucite-trachyte	Mte. Vico	R.C.R. 36	Effusive
11	I.5.2.2	.104	.094	.711	NoMl	Leucite-granite-porphyry	Brazil	W. T. 199	Mixture of rocks
12	I.5.2.3	.960	.093	.686	NoMo	Vulsinite	Astroni	R.C.R. 43	Effusive
13	I.5.2.3	.918	.093	.676	NoMl	Leucite-trachyte	Proceno	R.C.R. 43	Effusive
14	I.5.3.2	.989	.074	.716	NoMo	Augite-syenite	British Guiana	W.T. 205	Intrusive
15	I.6.1.3	.931	.112	.687	NoMl	Leucite-phonolite	Bracciano	R.C.R. 47	Effusive
16	I.6.1.3	.893	.101	.683	NoMo	Nephelite-syenite	Beemerville	W.T. 207	Intrusive
17	I.6.1.3	.923	.107	.656	NoMo	Nephelite-syenite	Siberia	A.J.S., XIII, 1902, 176	Intrusive
18	I.6.1.3	.982	.117	.690	NoMo	Leucite-tinguaite-vitrophyre	Portugal	W.T. 207	Vitreous; no leucite
19	I.6.1.3	.920	.089	.676	NoMl	Leucite-phonolite	Eifel	W.T. 207	Effusive
20	I.6.1.4	.891	.064	.701	NoMl	Leucite-phonolite	Eifel	W.T. 211	Effusive
21	I.6.2.4	.904	.043	.660	NoMl	Leucite (?) microsyenite	Madagascar	M.M. 205	Leucite doubtful; intrusive
22	I.7.1.3	.838	.120	.691	NlMl	Leucite-tephrite	Tavolato	R.C.R. 51	Effusive
23	I.7.1.3	.892	.094	.695	NoMo	Nephelite-syenite	Magnet Cove	W.T. 215	Intrusive
24	II.4.3.3	.990	.056	.671	NoMo	Biotite-latite	Mte. Cimino	R.C.R. 56	Normative quartz
25	II.5.1.2	.931	.099	.634	NoMo	Syenite	New So. Wales		Intrusive

APPENDIX II—*Continued*

No.	Symbol	SiO_2	K_2O	N	Norm and Mode	Name	Locality	Reference	Remarks
26	II.5.1.2	.967	.107	.698	NoMo	Tinguaite	Highwood Mts.	Bull. 237, 128	Intrusive
27	II.5.2.2	.955	.097	.683	NoMo	Vulsinite	Mte. Vico	R.C.R. 59	Effusive
28	II.5.2.2	.924	.071	.709	NoMo	Ciminite	Mte. Cimino	R.C.R. 63	Effusive
29	II.5.2.2	.955	.068	.742	NoMo	Ciminite	Mte. Cimino	R.C.R. 63	Effusive
30	II.5.2.2	.931	.094	.669	NoMl	Leucite-trachyte	Bagnorea	R.C.R. 67	Effusive
31	II.5.2.2	.920	.090	.678	NoMl	Leucite-trachyte	Mte. Vico	R.C.R. 67	Effusive
32	II.5.2.2	.869	.077	.700	NoMl	Leucite-tephrite	Mte. Vico	R.C.R. 72	Effusive
33	II.5.2.2	.851	.077	.647	NoMo	Durbachite	Durbach	W.T. 255	Intrusive; biotite
34	II.5.2.2	.940	.083	.722	NoMo	Selagite	Mte. Catini	W.T. 255	Effusive; biotite
35	II.5.2.3	.920	.081	.690	NoMo	Vulsinite	Mte. Vico	R.C.R. 75	Effusive
36	II.5.2.3	.946	.063	.682	NoMl	Vulsinite	Ischia	R.C.R. 75	Effusive
37	II.5.2.3	.912	.073	.683	NoMl	Vulsinite	Astroni	R.C.R. 75	Effusive
38	II.5.2.5	.740	.008	.563	NoMl	Leucite-basanite	Mte. Ferru	Unpublished	Effusive
39	II.5.3.2	.873	.080	.661	NoMl	Leucite-tephrite	Mte. Vico	R.C.R. 80	Effusive
40	II.5.3.2	.848	.077	.672	NoMl	Leucite-trachyte	Rocca Monfina	R.C.R. 83	Effusive
41	II.5.3.2	.854	.070	.695	NoMl	Leucite-tephrite	Toscanella	R.C.R. 86	Effusive
42	II.5.3.2	.847	.074	.672	NoMo	Minette	Plauen	W.T. 265	Intrusive; biotite
43	II.5.3.2	.837	.092	.683	NoMl	Sommaite	Mte. Somma	C.R. CXLI, 1190	Intrusive (?)
44	II.5.3.3	.928	.047	.724	NoMo	Biotite-latite.	Rocca Monfina	R.C.R. 88	Effusive; normative quartz
45	II.5.3.3	.882	.051	.659	NoMl	Leucite-banakite	Yell. Nat. Park	W.T. 267	Effusive
46	II.5.3.3	.875	.039	.674	NoMl	Leucite-shoshonite	Yell. Nat. Park	W.T. 267	Effusive; leucite doubtful
47	II.5.3.3	.859	.044	.642	NoMl	Leucite-banakite	Yell. Nat. Park	W.T. 267	Effusive
48	II.5.3.3	.829	.033	.666	NoMl	Leucite-tephrite	Bohemia	W.T. 271	Effusive
49	II.5.3.3	.861	.052	.671	NoMl	Sommaite	Mte. Somma	C.R. CLXI, 1190	Intrusive (?)
50	II.5.3.3	.835	.045	.678	NoMl	Sommaite	Mte. Somma	C.R. CLXI, 1190	Intrusive (?)
51	II.5.3.4	.872	.029	.675	NoMl	Leucite-tephrite	Bohemia	W.T. 283	Effusive
52	II.6.1.1	.909	.114	.804	NlMl	Wyomingite	Leucite Hills	W.R.T. 51	Effusive
53	II.6.1.2	.863	.081	.701	NoMl	Fergusite	Highwood Mts.	Bull. 237, 86	Intrusive; pseudo-leucite
54	II.6.1.3	.885	.089	.698	NoMo	Foyaite	Magnet Cove	W.T. 293	Intrusive
55	II.6.1.3	.882	.084	.682	NoMl	Leucite-tinguaite	Magnet Cove	W.T. 293	Intrusive; pseudo-leucite
56	II.6.1.3	.961	.098	.724	NoMo	Tinguaite	Judith Mts.	W.T. 293	Intrusive

APPENDIX II—*Continued*

No.	Symbol	SiO_2	K_2O	N	Norm and Mode	Name	Locality	Reference	Remarks
57	II.6.1.3	.958	.100	.738	NoMo	Tinguaite	Bearpaw Mts.	W.T. 295	Intrusive
58	II.6.1.3	.866	.082	.686	NoMo	Syenite-porphyry	Highwood Mts.	Bull. 237, 139	Intrusive
59	II.6.1.3	.934	.093	.733	NoMo	Nephelite-syenite	Brazil	W.T. 295	Intrusive
60	II.6.1.3	.919	.074	.630	NoMo	Syenite	New South Wales	P.R.S.N.S.W. XXXVII, 341	Intrusive
61	II.6.1.4	.901	.072	.701	NoMl	Leucite-tinguaite	Magnet Cove	W.T. 295	Intrusive; pseudo-leucite
62	II.6.1.4	.903	.056	.649	NoMl	Leucite-porphyry	Kilimanjaro	R.F. 392	Effusive
63	II.6.1.4	.891	.062	.662	NoMl	Leucite-porphyry	Kilimanjaro	R.F. 392	Effusive
64	II.6.2.2	.914	.111	.688	NoMl	Leucite-tephrite	Mte. Vico	R.C.R. 92	Effusive
65	II.6.2.2	.853	.113	.670	NlMl	Leucite-tephrite	Rocca Monfina	R.C.R. 92	Effusive
66	II.6.2.2	.845	.100	.675	NlMl	Leucite-tephrite	Bracciano	R.C.R 97	Effusive
67	II.6.2.2	.839	.100	.676	NlMl	Leucite-tephrite	Bracciano	R.C.R. 97	Effusive
68	II.6.2.2	.838	.080	.680	NlMl	Leucite-tephrite	Orvieto	R.C.R. 101	Effusive
69	II.6.2.3	.856	.071	.679	NoMo	Nephelite-felsite	Magnet Cove	W.T. 297	Intrusive
70	II.6.2.3	.828	.053	.684	NoMo	Covite	Magnet Cove	W. T. 297	Intrusive
71	II.6.2.3	.868	.065	.716	NoMo	Syenite	Highwood Mts.	Bull. 237, 92	Intrusive
72	II.6.2.3	.835	.080	.660	NoMo	Syenite	Highwood Mts.	Bull. 237, 96	Intrusive
73	II.6.2.3	.833	.091	.651	NlMo	Syenite	Highwood Mts.	Bull. 237, 92	Intrusive
74	II.6.2.4	.832	.040	.704	NoMl	Leucite-kulaite	Kula	W.T. 299	Effusive
75	II.6.2.4	.806	.042	.685	NoMo	Kulaite	Kula	W.T. 299	Effusive
76	II.6.2.5	.748	.008	.610	NoMl	Leucite-basanite	Mte. Ferru	Unpublished	Effusive
77	II.6.3.2	.821	.056	.702	NoMl	Leucite-basalt	Ernici	W.T. 301	Effusive
78	II.7.1.3	.866	.104	.725	NlMl	Leucite-tinguaite	Bearpaw Mts.	W.T. 303	Intrusive; pseudo-leucite
79	II.7.1.3	.885	.073	.736	NoMo	Tinguaite	Brazil	W.T. 303	Intrusive
80	II.7.1.3	.869	.086	.711	NlMl	Leucitophyre	Brazil	W.T. 303	Effusive
81	II.7.1.3	.833	.088	.681	NlMl	Leucite-tinguaite	Beemerville		Intrusive; pseudo-leucite(?)
82	II.7.2.2	.794	.080	.721	NlMl	Leucite-tephrite	Vesuvius	R.C.R. 104	Effusive
83	II.7.2.2	.798	.087	.684	NlMl	Leucitite	Bracciano	R.C.R. 109	Effusive
84	II.7.2.2	.787	.081	.698	NlMl	Leucitite	Alban Hills	R.C.R. 113	Effusive
85	II.7.2.2	.802	.084	.672	NlMl	Leucite-tephrite	Vesuvius	R.C.R. 116	Effusive; vitreous
86	II.7.2.2	.795	.081	.702	NlMl	Leucite-tephrite	Vesuvius	R.C.R .118	Effusive

APPENDIX II—*Continued*

No.	Symbol	SiO_2	K_2O	N	Norm and Mode	Name	Locality	Reference	Remarks
87	II.7.2.2	.817	.096	.693	NlMl	Leucite-tephrite	Vesuvius	W.T. 305	Effusive
88	II.7.2.4	.708	.049	.669	NlMl	Hauynophyre	Mte. Vulture	W.T. 305	Effusive
89	II.7.3.2	.811	.069	.643	NlMl	Leucitophyre	Vesuvius	W.R.T. 53	Effusive
90	II.7.3.3	.790	.063	.716	NlMl	Leucite-tephrite	Rocca Monfina	W.T. 305	Effusive
91	II.7.3.3	.786	.070	.697	NlMl	Leucitophyre	Vesuvius	W.R.T. 53	Effusive
92	II.7.3.4	.651	.019	.652	NlMo	Nephelinite	Rhöngebirge	W.T. 305	Effusive; vitreous
93	II.7.3.4	.651	.027	.630	NlMo	Nephelite-basalt	Rhöngebirge	W.T. 305	Effusive; vitreous
94	II.8.1.4	.804	.062	.741	NlMo	Nephelinite	Odenwald	W.R.T. 53	Effusive; vitreous
95	II.8.2.4	.635	.023	.615	NlMo	Biotite-ijolite	Magnet Cove	W.T. 307	Intrusive; biotite
96	II.8.2.4	.659	.060	.600	NlMl	Hauynophyre	Mte. Vulture	Unpublished	Effusive
97	II.9.1.3	.740	.087	.664	NlMl	Leucite-syenite	Magnet Cove	W.T. 307	Intrusive; pseudo-leucite
98	II.9.1.3	.761	.074	.690	NlMo	Nephelite-porphyry	Kola	W.T. 307	Intrusive
99	II.9.1.3	.775	.072	.697	NlMl	Leucitite	Kamerun	W.T. 307	Effusive
100	II.9.1.4	.758	.045	.731	NlMo	Urtite	Kola	W.T. 307	Intrusive
101	II.9.1.4	.757	.036	.719	NlMo	Urtite	Kola	W.T. 307	Intrusive
102	II.9.1.4	.755	.037	.728	NlMo	Urtite	Kola	W.T. 307	Intrusive
103	II.9.1.4	.717	.032	.699	NlMo	Ijolite	Kola	W.T. 307	Intrusive
104	III.5.1.1	.903	.126	.686	NoMl	Orendite	Leucite Hills	W.T. 313	Effusive; biotite
105	III.5.1.1	.901	.125	.671	NoMl	Orendite	Leucite Hills	W.T. 313	Effusive; normative quartz
106	III.5.1.1	.893	.119	.661	NoMl	Wyomingite	Leucite Hills	W.T. 313	Effusive; biotite
107	III.5.1.1	.846	.079	.659	NoMl	Jumillite	Murcia	R.F. 290	Effusive
108	III.5.1.2	.814	.061	.517	NoMl	Jumillite	Murcia	R.F. 290	Effusive
109	III.5.2.2	.840	.080	.672	NoMo	Syenitic-lamprophyre	Colorado	J.G. XIV, 168	Intrusive
110	III.5.2.2	.871	.064	.681	NoMo	Syenite-porphyry	Maine	J.G. XIV, 179	Intrusive
111	III.5.2.3	.789	.040	.683	NoMl	Leucite-absarokite	Yell. Nat. Park	W.T. 313	Effusive
112	III.5.2.4	.781	.028	.606	NoMl	Leucite-tephrite	Bohemia	W.T. 315	Effusive; normative quartz
113	III.5.3.4	.788	.023	.679	NoMl	Leucite-absarokite	Yell. Nat. Park	W.T. 321	Effusive
114	III.6.1.1	.837	.104	.682	NlMl	Wyomingite	Leucite Hills	W.T. 339	Effusive
115	III.6.1.3	.833	.034	.708	NoMo	Shonkinite	Bearpaw Mts.	W.T. 339	Intrusive
116	III.6.2.3	.827	.060	.724	NlMl	Leucite-shonkinite	Highwood Mts.	Bull. 237, 108	Intrusive; pseudo-leucite
117	III.6.2.3	.800	.054	.675	NoMl	Leucite-basalt	Highwood Mts.	Bull. 237, 168	Effusive

APPENDIX II—*Continued*

No.	Symbol	SiO_2	K_2O	N	Norm and Mode	Name	Locality	Reference	Remarks
118	III.6.2.3	.779	.040	.692	NoMo	Shonkinite	Highwood Mts.	Bull. 237, 102	Intrusive
119	III.6.2.3	.816	.053	.692	NoMo	Shonkinite	Little Belt Mts.	W.T. 341	Intrusive
120	III.6.2.3	.828	.059	.692	NoMl	Leucitophyre	Persia	W.T. 341	Effusive
121	III.6.2.4	.731	.031	.609	NoMl	Leucite-basanite	Kaiserstuhl	W.T. 341	Effusive
122	III.6.2.4	.797	.043	.670	NoMl	Leucite-tephrite	Bohemia	W.T. 343	Effusive
123	III.6.3.2	.794	.051	.716	NlMl	Leucite-tephrite	Mte. Somma	C.R. CXLI, 1192	Effusive
124	III.6.3.3	.708	.029	.669	NlMo	Monchiquite	Castle Mts.	W.T. 343	Intrusive; glass or analcite
125	III.6.3.4	.632	.022	.601	NlMo	Hornblendite	Norway	W.T. 345	Intrusive
126	III.6.3.4	.656	.019	.633	NlMl	Leucite-monchiquite	New South Wales	R.G.S.N.S.W. VIII, 50	Effusive
127	III.6.4.3	.643	.015	.631	NlMo	Ariegite	Pyrenees	W.T. 347	Intrusive
128	III.6.4.3	.686	.017	.671	NlMl	Leucite-basalt	Vogelsberg	W.T. 347	Effusive
129	III.6.4.3	.644	.007	.636	NlMo	Limburgite	Cape Verde Is.	W.T. 347	Effusive; vitreous
130	III.7.1.3	.798	.056	.700	NlMo	Malignite	Ontario	W.T. 347	Intrusive
131	III.7.2.2	.790	.073	.714	NlMl	Leucitite	Lake Bolsena	R.C.R. 124	Effusive
132	III.7.2.3	.767	.062	.665	NlMl	Minette	Highwood Mts.	Bull. 237, 144	Intrusive; biotite
133	III.7.2.4	.665	.038	.633	NlMo	Nephelite-basalt	Löbauerberg	W.T. 349	Effusive; vitreous
134	III.7.2.4	.668	.035	.611	NlMl	Leucite-nephelinite	Kamerun	W. T. 349	Effusive
135	III.7.2.4	.666	.038	.614	NlMl	Leucite-nephelinite	Kamerun	W.T. 349	Effusive
136	III.7.2.4	.655	.016	.548	NoMo	Hauynophyre	Kamerun	W.T. 349	Effusive
137	III.7.2.4	.711	.016	.693	NlMo	Basalt	Cape Verde Is.	W.R.T. 59	Effusive
138	III.7.2.4	.671	.016	.623	NoMl	Leucite-monchiquite	New South Wales	R.G.S.N.S.W. VII, 302	Effusive
139	III.7.3.2	.748	.039	.725	NlMl	Leucite-basanite	Lake Bolsena	R.C.R 127	Effusive
140	III.7.3.2	.607	.032	.576	NlMo	Ouachitite	Hot Springs	W.T. 349	Intrusive; biotite
141	III.7.3.4	.709	.023	.680	NlMo	Monchiquite	Orkney Is.	W.T. 351	Intrusive; vitreous
142	III.7.3.4	.720	.013	.701	NlMo	Nephelite-basalt	Hesse	W.T. 351	Effusive; vitreous
143	III.7.3.4	.695	.011	.671	NlMo	Basalt	Bohemia	W.T. 351	Effusive; vitreous
144	III.7.3.4	.656	.016	.638	NlMo	Nephelite-basalt	Bohemia	W.T. 351	Effusive; vitreous
145	III.7.3.4	.656	.036	.603	NlMo	Hauynophyre	Kamerun	W.T. 351	Effusive; vitreous

APPENDIX II—*Continued*

No.	Symbol	SiO_2	K_2O	N	Norm and Mode	Name	Locality	Reference	Remarks
146	III.7.3.4	.603	.019	.593	NlMo	Melilite-basalt	Cape Colony	A.R.G.C.C.G.H. 1903, 51	Effusive; melilite
147	III.7.3.4	.676	.021	.651	NlMo	Nephelite-basalt	Rossberg	W.R.T. 59	Effusive; vitreous(?)
148	III.7.3.5	.679	.006	.672	NlMo	Nephelite-basalt	Rhöngebirge	W.T. 351	Effusive; much nephelite
149	III.8.1.2	.775	.092	.657	NlMl	Leucitite	Bearpaw Mts.	W.T. 351	Effusive
150	III.8.1.2	.753	.074	.668	NlMl	Leucite-basalt	New South Wales	R.G.S.N.S.W. VII, 302	Effusive
151	III.8.2.2	.771	.068	.716	NlMl	Leucitite	Lake Bolsena	R.C.R. 131	Effusive
152	III.8.2.2	.771	.091	.687	NlMl	Leucitite	Ernici	R.C.R. 135	Effusive
153	III.8.2.2	.784	.080	.712	NlMl	Leucitite	Ernici	R.C.R. 135	Effusive
154	III.8.2.2	.767	.096	.676	NlMl	Leucitite	Alban Hills	R.C.R. 139	Effusive
155	III.8.2.2	.768	.055	.720	NlMl	Missourite	Highwood Mts.	Bull. 237, 117	Intrusive
156	III.8.2.3	.687	.038	.650	NlMo	Nephelinite	Laacher See	W.R.T. 59	Effusive; vitreous
157	III.8.2.3	.606	.039	.564	NlMo	Melilite-basalt	Hegau	W.T. 351	Effusive; melilite
158	III.8.2.4	.696	.042	.649	NlMo	Ijolite	Magnet Cove	W.T. 353	Intrusive
159	III.8.2.4	.649	.019	.629	NlMo	Biotite-ijolite	Magnet Cove	W.T. 353	Intrusive; biotite
160	III.8.2.4	.720	.043	.662	NlMo	Theralite	Crazy Mts	W.T. 353	Intrusive
161	III.8.2.4	.711	.038	.677	NlMo	Nephelite-basanite	Hesse	W.T. 353	Effusive; vitreous
162	III.8.2.4	.669	.040	.630	NlMl	Leucitic-nephelinite	Kamerun	W.T. 353	Effusive
163	III.8.2.4	.640	.026	.607	NlMl	Leucitic-nephelinite	Kamerun	W.T. 353	Effusive
164	III.8.2.4	.661	.033	.626	NlMo	Teschenite	Cape Verde Is.	W.T. 353	Intrusive; biotite
165	III.8.2.4	.661	.033	.620	NlMo	Olivine-diabase	Cape Verde Is.	W.R.T. 59	Intrusive; vitreous(?)
166	III.8.2.5	.769	.010	.758	NlMo	Nephelinite (andesite)	Grenada	W.T. 353	Effusive; vitreous
167	III.9.1.2	.711	.085	.625	NlMo	Madupite	Leucite Hills	W.T. 353	Effusive; vitreous
168	III.9.1.4	.751	.031	.737	NlMo	Nephelinite	Odenwald	W.R.T. 61	Effusive; vitreous
169	III.9.1.4	.747	.039	.716	NlMo	Nephelinite	Odenwald	W.R.T. 61	Effusive; vitreous
170	III.9.1.4	.728	.030	.690	NlMo	Ijolite	Kola	W.T. 353	Intrusive
171	III.9.1.5	.701	.020	.684	NlMo	Ijolite	Kola	W.T. 353	Intrusive
172	IV.$1^{4}.1^{2}.1$	.701	.012	.691	NlMo	Limburgite	Habichtswald	W.T. 355	Effusive; vitreous
173	IV.$1^{2}.1^{2}.1$	.714	.007	.719	NlMo	Olivine-basalt	Grenada	W.T. 355	Effusive; vitreous
174	IV.$1^{3}.1^{2}.1$	.789	.028	.695	NoMl	Jumillite	Murcia	R.F. 305	Effusive

APPENDIX II—*Continued.*

No.	Symbol	SiO_2	K_2O	N	Norm and Mode	Name	Locality	Reference	Remarks
175	IV.1^{4}1^{2}3	.672	.012	.673	NlMo	Nephelite-basalt	Rhöngebirge	W.T. 357	Effusive; vitreous (?)
176	IV.1^{5}1^{1}2	.654	.006	.648	NlMo	Hornblende-peridotite	Pyrenees	W.T. 357	Intrusive
177	IV.1^{5}1^{3}2	.691	.079	.711	NlMl	Venanzite	Umbria	W.T. 357	Effusive
178	IV.2^{1}1^{3}2	.751	.009	.746	NlMo	Pyroxenite	Norway	W.T. 359	Intrusive
179	IV.2^{2}1^{2}2	.637	.024	.606	NlMo	Melilite-basalt	Hegau	W.T. 359	Effusive
180	IV.2^{2}1^{2}2	.635	.014	.622	NlMo	Nephelite-basalt	Rhöngebirge	W.T. 359	Effusive; vitreous (?)
181	IV.2^{2}1^{2}2	.665	.020	.659	NlMo	Nephelite-basalt	Löbauerberg	W.T. 359	Effusive; vitreous (?)
182	IV.2^{2}1^{2}2	.726	.064	.636	NlMl	Leucite-basalt	New South Wales	R.G.S.N.S.W., VII, 302	Effusive
183	IV.2^{2}1^{3}2	.640	.008	.640	NlMo	Jacupirangite	Magnet Cove	W.T. 361	Intrusive
184	IV.2^{3}1^{2}2	.672	.012	.653	NlMo	Nephelite-basalt	Texas	W.T. 361	Effusive; vitreous (?)
185	IV.2^{3}1^{2}2	.665	.011	.650	NlMo	Nephelite-basalt	Texas	W.T. 361	Effusive; vitreous (?)
186	IV.2^{3}1^{2}2	.648	.017	.640	NlMo	Melilite-basalt	Hegau	W.T. 361	Intrusive
187	IV.2^{3}1^{2}2	.609	.017	.591	NlMo	Melilite-basalt	Hegau	W.T. 361	Effusive
188	IV.2^{3}1^{2}2	.633	.021	.625	NlMo	Melilite-basalt	Westphalia	W.T. 363	Effusive
189	IV.231^{2}2	.658	.020	.636	NlMo	Nephelite basalt	Löbauerberg	W.T. 363	Effusive; vitreous
190	IV.231^{2}2	.660	.008	.659	NlMo	Nephelite-basalt	Silesia	W.R.T. 61	Effusive
191	IV.241^{2}2	.633	.007	.628	NlMo	Melilite-basalt	Texas	W.T. 363	Effusive
192	IV.241^{2}2	.653	.016	.629	NlMo	Nephelite-basalt	Hesse-Cassel	W.T. 363	Effusive
193	IV.2^{5}1^{1}3	.583	.058	.500	NlMo	Biotite-peridotite	Harz Mts.	W.T. 365	Intrusive
194	IV.3^{2}1^{2}2	.597	.016	.578	NlMo	Melilite-basalt	Hegau	W.T. 365	Effusive
195	IV.3^{4}1^{2}2	.593	.019	.568	NlMo	Melilite-basalt	Hegau	W.T. 365	Effusive

ABBREVIATIONS

A.J.S=	*American Journal of Science* (New Haven)
A.R.G.C.C.G.H.=	*Annual Report of the Geological Commission of the Cape of Good Hope.*
Bull. 237=	Pirsson, "Igneous Rocks of the Highwood Mountains, Montana," *Bulletin No. 237*, U. S. Geological Survey (1905).
C.R.=	*Comptes Rendus de l'Academie des Sciences* (Paris).
J.G.=	*Journal of Geology* (Chicago).
R.C.R.=	Washington, *The Roman Comagmatic Region*, Carnegie Publication No. 57 (1906).
R.F.=	*Rosenbusch Festschrift* (Stuttgart, 1906).
R.G.S.N.S.W.=	*Records of the Geological Survey of New South Wales.*
W.R.T.=	Roth's *Tabellen*, arranged by Washington. *Professional Paper No. 28*, U. S. Geological Survey (1904).
W.T.=	Washington's *Tables*, 1884–1900. *Professional Paper No. 14*, U. S. Geological Survey (1903).
Nl=	leucite present in the norm.
No=	leucite not present in the norm.
Ml=	leucite present in the mode.
Mo=	leucite not present in the mode.

STUDIES FOR STUDENTS[1]

THE RECENT ADVANCE IN SEISMOLOGY

WILLIAM HERBERT HOBBS
University of Michigan

II. THE CO-ORDINATED "DISTANT" STUDY OF EARTHQUAKES

As already stated, in the first of these papers,[2] the one to whom we owe most for the exploitation of this new field for seismological study is Professor John Milne, whose later achievements crown a lifetime devoted to geophysical researches.[3] In 1883 he wrote: "It is not unlikely that every large earthquake might with proper appliances be recorded at any point on the land surface of the globe." Six years later the late von Rebeur-Paschwitz detected, in the photographic records of a very delicate horizontal pendulum, movements which he traced to earthquakes at a very great distance. These studies, published in 1895,[4] were thus the first to verify the prophetic

[1] Owing to the rapid development of the New Seismology, few treatises upon the subject have appeared. In addition to the briefer statements in Milne's *Seismology* (London, 1898) and Dutton's *Earthquakes* (London and New York, 1904), the student may with profit consult *Handbuch der Erdbebenkunde* by A. Sieberg, secretary of the German Chief Station for Earthquake Study at Strassburg. The subject will be more elaborately treated in Sieberg's *Geophysik*, soon to appear, and in *La science séismologique* by Count de Montessus de Ballore, which it is expected will also be issued during the present season. The most satisfactory treatment of the more strictly geological side of the subject of earthquakes is to be found in *Erdbebenkunde, die Methoden ihrer Beobachtung*, by Rudolph Hoernes (Leipzig, 1893).

[2] *Journal of Geology*, Vol. XV, pp. 288–97.

[3] John Milne, "Seismological Observations and Earth Physics," *Geographical Journal*, London, Vol. XXI (1903), pp. 1–25, map.

[4] E. von Rebeur-Paschwitz, "Europäische Beobachtungen des grossen japanischen Erdbebens vom 22. März 1894, und des venezuelanischen Erdbebens vom 28. April 1894, nebst Untersuchungen über die Fortpflanzungsgeschwindigkeit dieser Erdbeben," *Petermann's Mitteilungen*, Vol. XLI (1895), pp. 13–21, 39–42. (See also *Beiträge zur Geophysik*, Vol. II.)

words of Milne uttered twelve years earlier.[1] Today seismologists have so perfected recording instruments that at all first-class stations they are able to report great earthquakes which have occurred anywhere upon the globe, and less than a half-hour after their occurrence, the news having been telegraphed to them by the earth itself through, it may be, its entire diameter; and to have their reports confirmed by the telegraphic cables some hours or days later, according as cables have or have not been fractured. In his observing-station at Shide, upon the Isle of Wight, Professor Milne has been able to reassure anxious friends after the press announcement of a terrible earthquake in a nearly antipodal region, and confirm the fact from later press dispatches that the earlier report was a fabrication.[2]

The possibility of fixing the location of the disturbed region in the case of one of these so-called "unfelt quakes" is inherent in the fact that the waves of macroseisms are transmitted apparently not only through the mass of the globe, but also along its circumference. Those waves which first reach the station, the "preliminary tremors" of the seismogram (see Fig. 1), appear to come by the direct route through the earth's mass, as is pretty clearly shown by their constancy of velocity when the station is distant, and their variability of speed when the disturbed district is near. For the long distances the velocity is quite uniform and about 10 kilometers per second, so that the diameter of the earth is traversed in about 20 minutes.

The Japanese school of seismologists have generally held that the waves which produce these preliminary tremors in the seismogram

[1] An excellent account of the growth of the new methods of study may be found in the paper by W. Schlüter, "Schwingungsart und Weg der Erdbebenwellen," *Beiträge zur Geophysik*, Vol. V (1901), pp. 314–59.

[2] For a description of modern seismographs see C. E. Dutton, *Earthquakes in the Light of the New Seismology* (London and New York, 1904), in which the Italian instruments designed by Agemennone are described with especial fulness; C. F. Marvin, "The Omori Seismograph at the Weather Bureau" (*Monthly Weather Review*, June, 1903, pp. 1–8) and "Improvements in Seismographs with Mechanical Registration" (*ibid.*, May, 1906, pp. 1–6), where the Borsch-Omori instruments with Marvin's excellent improvements are described; A. Sieberg, *Handbuch der Erdbebenkunde* (Braunschweig, 1904), where the Wiechert Astatic Seismometer, the most modern and satisfactory instrument, though the most difficult to manage, is described and figured. Much may be learned from the trade catalogues of Spindler & Hoyer, of Göttingen, the manufacturers of the Wiechert instrument, and of J. &. A. Borsch, 15 Münstergasse, Strassburg, the European manufacturers of the Omori type of pendulum.

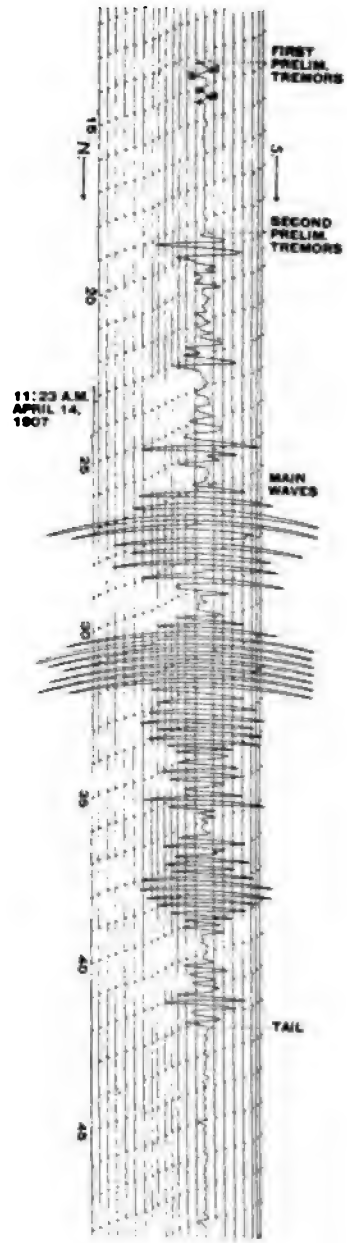


FIG. 1.—Record of the north-south component of the wave-motion rom the earthquake in Mexico of April 15, 1907, as registered on a Bosch-Omori horizontal pendulum at the U. S. Weather Bureau in Washington, D. C. (By courtesy of Professor C. F. Marvin.) The beginnings of the first and second preliminary tremors and of the main waves have been indicated. The intervals are minutes.

have an arcual path similar to, but deeper than, the "large waves," which follow them in time and are, as all agree, surface waves.[1] The velocity of these first waves, reckoned on this basis, would be about 14 kilometers per second instead of 10. Perhaps the strongest argument against this view is found in the known constants of surface rocks, which do not permit such a velocity. (See below, p. 400.)

It seems likely that the value assigned for the velocity of the direct waves may be subsequently considerably modified, since it has been largely based upon the records of the light Milne pendulums. Some sacrifice the pioneer must always make, and the standard Milne instrument suffers in comparison with the later German, Japanese, and Italian types, not only because of its lightness, but because the expense of photographic paper has necessitated a slow movement of the feeding-drum and a resulting contracted scale of the diagram. At the Batavia station a Milne and a Rebeur instrument have been installed side by side, and a comparison of the records now shows for the first time that the registration of shocks begins from one to ten minutes earlier upon the Rebeur pendulum.[2] The "preliminary tremors" of the Milne instrument may belong in the second phase of the records from more sensitive instruments.

For origins less than 1,000 kilometers distant such tremors do not appear in the seismogram, and it is supposed that they are combined with the large waves and reach the station at a speed of about 3.3 kilometers per second, with little doubt because of the lower rock densities which are traversed along the shorter and hence "crustal" chords.

The Earthquake Investigation Committee of Japan in 1894 instituted, at the suggestion of Professors Sekiya and Omori, a system of triangulation involving the use of four stations provided with exactly similar instruments and connected by telegraph to convey uniform ticks from a chromometer. The distances between the stations varied from 2.29 to 10.86 kilometers. All instruments being started by the same earthquake, the recognition of special marked vibrations

[1] Baron Dairoku Kikuchi, "Recent Seismological Investigations in Japan," *Pub. E.I. C.* (Foreign Languages), No. 19, 1904, p. 61.

[2] E. Rudolph, "Ostasiatischer Erdbebenkatalog" (1904), *Gerland's Beiträge zur Geophysik*, Vol. VIII, 1906 (1907), pp. 113–217.

allowed the times of arrival of the same shocks to be compared. The result obtained for the velocity of the surface waves of large amplitude (Section 5) was 3.3 kilometers per second, or the same as by the usual method.

It is a general observation that shocks are more violent at the earth's surface than they are in mines. At Przibram, in Bohemia, two similar modern Wiechert astatic pendulums have been installed, the one at the surface of the ground and the other in a mine 1,150 meters (or about 3,700 feet) under ground. The falling-off in amplitude of the shocks at the lower station is confirmed, but otherwise the seismograms appear to be nearly identical.

A most important study, and almost unique within its field, has been made by Nagaoka[1] upon the elastic constants of rocks. From his results he has obtained the velocity of propagation for waves in rock material, and these correspond fairly well with those actually measured by seismometers at the time of earthquakes.

The velocity of propagation of plane longitudinal waves within an infinite medium of steel is 6.2 kilometers per second. Within the earth's crust it is hardly to be expected that constant velocities will be obtained, since the crust is not homogeneous, and, further, is not isotropic, but quasi-crystalline. Several of the rocks investigated gave values for velocity as high as 6 and 7 kilometers per second. Nagaoka shows that a relation exists between the density and the elastic constant. In passing from Cenozoic to Archean rocks, with an increase of density from 2 to 3, the modulus of elasticity increased more than ten times in certain specimens. The mean earth density is 5.5+, and Nagaoka argues for a stratum of this density quite near to the surface. His studies have since been continued by Kusakabe,[2] using improved apparatus. For the velocity of propagation of waves in various types of Archean rocks Kusakabe

[1] H. Nagaoka, "Elastic Constants of Rocks and the Velocity of Seismic Waves," *Publications of the Earthquake Investigation Committee in Foreign Languages*, No. 4 (Tokyo, 1900), pp. 47–67.

[2] S. Kusakabe, "Modulus of Rigidity of Rocks and Hysteresis Function," *Journal of the College of Science*, Imperial University, Tokyo, Vol. XIX (1904), pp. 1–40, 22 plates and 53 figures. See also by the same author "A Kinetic Measurement of the Modulus of Elasticity for 158 Specimens of Rocks and a Note on the Relation between the Kinetic and Static Moduli," *Pub. E. I. C.* (Foreign Languages), No. 22 B, 1906, pp. 27–49.

obtained the average value 2.54. The average of all the rocks tested is a value slightly less than that of the large or surface earthquake waves.

The apparently uniform velocity of propagation of elastic earthquake waves through the core of the earth is a revelation of the first order of magnitude, for it indicates for the earth a uniformity of composition, and, moreover, a rigidity equal to one and a half times that of the hardest steel. The preliminary tremors from the great Indian earthquake of 1897, as received at Rocca di Papa, had an estimated period of 0.5 to 0.8 of a second, while their amplitude was but a fraction of a millimeter.

Following the preliminary tremors from a macroseism,[1] the seismogram indicates a second phase of larger disturbances; after which come the "large waves," which in the case of the quake above mentioned had a complete period of 22 seconds, a length of 34 miles, and a rise and fall of no less than 20 inches. These waves appear, therefore, to travel like a slow swell along the earth's surface.

Another fact of great interest is that the large waves gain in period of vibration and lose amplitude the farther they travel, so that an experienced observer can roughly estimate the distance of the disturbed area from the period of vibration of the waves. With fairly uniform rates of propagation established for both the direct and the surface waves which originate at any distant origin, the difference in time between the arrival of the preliminary tremors and that of the large waves gives a further measure of the distance of the origin from the observing-station. For example, a distance of 80 degrees corresponds to a time interval separating first preliminary tremors and first large waves of about 35 minutes.

Láska has derived surprisingly simple formulas for fixing the distance of the seat of disturbance in the case of remote earthquakes.[2] If V_1 be the time in minutes of the beginning of the preliminary

[1] Great confusion exists because of the different uses of the terms "macroseism" and "microseism," as well as of the adjectives derived from them. The usage here is that of both Milne and de Montessus, which makes "macroseism" apply to the greater disturbance on the ground.

[2] W. Láska, "Ueber der Berechnung von Fernbeben," *Mittheilungen der Erdbeben-Kommission der k. Akademie der Wissenschaften zu Wien*, N. F., No. 14 (1903), pp. 1–13.

tremors, V_2 that of the second preliminary phase,[1] and B that of the main or large waves in the seismograph; and if Δ be the distance in megameters (1 megameter equals 1,000 kilometers), then

$$1+\Delta=V_2-V_1$$

and

$$3\Delta=B-V_1\,.$$

Benndorf has proven by many determinations the correctness of these formulas,[2] which are known as "Láska's Rules," and which may be stated in simple form as follows:

1. *The duration of the first preliminary tremors in minutes, less one, is the distance of the seat of disturbance in megameters.*

2. *The duration of all preliminary vibrations in minutes, less one, is thrice the distance of the seat of disturbance in megameters.*

An illustration of the precision in the measurement of distance with unfelt quakes is given by Alfani, the director of the Ximeniana station at Florence, for the Indian earthquake of April, 1905,[3] the error in determining the distance being only 32 kilometers if the geographic center of the affected district be regarded as the starting-point of the shocks.

Omori, on the assumption that the velocity of the waves which produce the first preliminary tremors (over an arcual path) is 13.7 kilometers per second, and that the velocity of the second preliminary tremors is 7.2 kilometers per second, has deduced a formula for finding the time of occurrence of an earthquake from the observations at a distant station.[4]

His formula is

$$t_0 = t_1 - 1.165\, y_1$$

where t_0 is the time of occurrence of the earthquake, t_1 the commence-

[1] Laska finds that earthquakes less than 500 kilometers distant produce no second preliminary phase in the seismograph.

[2] H. Benndorf, "Ueber die Art der Fortpflanzung der Erdbebenwellen im Erdinnern," *Mitth. d. Erdbeben-Kom. d. k. Acad. d. Wiss. z. Wien*, N. F., No. 29 (1905), p. 19.

[3] P. G. Alfani, "Il terremoto d'India del 4 Aprile, 1905, e le registrazioni sismiche all' osservatorio Ximeniana di Firenze," *Rivista geografica Italiana*, Anno XII (1905), fasc. V, pp. 1–6.

[4] F. Omori, "On the Estimation of the Time of Occurrence at the Origin of a Distant Earthquake from the Duration of the First Preliminary Tremors Observed at Any Place," *Bull. E. I. C.*, Vol. I, No. 1 (1907), pp. 1–4.

ment time of the earthquake at the distant observing station, and y_1 the duration of the first preliminary tremors reckoned in seconds. The time is thus obtained through subtracting from the time when the record begins the duration in seconds of the first preliminary tremors after multiplying by the factor 1.165.

Careful analysis of earthquake records shows that the large waves may be further divided into four sections, designated the third, fourth, fifth, sixth, and sometimes additional sections of the seismogram (the two phases of the preliminary tremors being included in the numeration). The vibrations of the third section are few and slow, those of the fourth section are somewhat quicker and of very large amplitude, while those of section 5 are of much shorter period and of large amplitude. The durations of these different sections of the complete earthquake record are roughly equal to one another, the third and fourth sections being taken together. The amplitude is greatest in the fourth and fifth sections. The feeble vibrations which end the seismogram are called its "tail."

It has been rather generally held as a theoretic proposition that the direct waves which produce the preliminary tremors of the seismogram are longitudinal—that is, compressional—vibrations; whereas the "large" or "main" waves vibrate in the plane transverse to the line of propagation. A decisive experimental proof of the correctness of this view seems to have been happily furnished by the registration of the recent Kingston earthquake of January 14, 1907, by the seismograph of the U. S. Weather Bureau.[1] The two Borsch-Omori pendulums of the bureau are so placed as to record the north-south and the east-west components of the wave motion. Now it happens that the port at Kingston, which is something more than 1,400 miles distant from Washington, differs in longitude by only 15 minutes. For our purposes, therefore, Kingston may be considered as located upon the meridian of Washington. Practically *no preliminary tremors were registered in the east-west direction* at the time of the earthquake, though a very distinct series was recorded in the north-south direction. Notwithstanding this difference, the main waves appeared at practically the same instant in the two records, but

[1] C. F. Marvin, "The Kingston Earthquake," *Monthly Weather Review*, January 22, 1907, pp. 1–4.

the amplitude of the east-west component was about five times that of the north-south component.

The deep significance of these modern seismograms having been recognized, the necessity for co-ordinating the work of different observers at once became apparent; for, if the distance of an earthquake origin from three or more stations could be determined, its location could naturally be fixed with much greater precision and accuracy. Under the leadership of Milne, the British Association has secured the co-ordination of the work of some forty-five stations well distributed over the surface of the globe, where observations are made upon a uniform type of instrument. All reports are forwarded to a central committee of the association, which makes comparison, and once in six months issues a report that is mailed to all the stations for further study.

Japan, with its relatively small but widely extended territory, has at present, besides its *Central Meteorological Observatory* and the *Laboratory of the Seismological Institute of the Imperial University* (both at Tokyo), seventy-one local stations provided with seismographs, and 1,437 other stations scattered throughout Japan. The seventy-one stations of the higher class receive standard time by telegraph from the central station at Tokyo.

In Italy the *Central Office for Meteorology and Geodynamics*, directed by Professor Luigi Palazzo, co-ordinates the work of fifteen seismological stations of the first rank. For collecting information upon Italian earthquakes there are 150 regular correspondents well distributed through the peninsula and Sicily, and 650 other persons who have agreed to telegraph an immediate report to the central office when any earthquake shock has been perceived by them. Since 1895 the data thus collected have been regularly published in the *Bollettino della Società sismologica Italiana.*

Germany has established some twelve stations of the first rank, in addition to the head station at Strassburg, where may be found the highest development of instrumental refinement in earthquake study. Here have been held the international conferences upon earthquakes, and here was founded in 1903 the International Seismological Association. The organ of the association, the *Beiträge zur Geophysik*, is edited by Professor G. Gerland, the director of the station, from

which also the annual catalogue of seisms is regularly issued. The staff included Professors E. Rudolph, Dr. C. Mainke, and Mr. A. Sieberg, all highly trained seismologists. Germany is soon to inaugurate a system of co-ordinated distant stations, in which will be included Samoa, Kiao-chau, German East Africa, and the Bismarck Archipelago.

After Great Britain no nation has better opportunities for establishing a co-ordinated system of earthquake stations than the United States. Coming late into the field, it will not be required to make the sacrifices of the pioneer on account of earlier and cruder instruments, and its isolated outlying territory is admirably distributed for the purpose in view. With first-class stations and modern instruments at Washington, in New England, California, Alaska, Panama, Honolulu, Tutuila, Manila, Guam, Cuba, and Porto Rico, much might be accomplished to offset the minor rôle which the nation has thus far played in the great advance of seismology. At the last annual meeting of the American Association for the Advancement of Science, held in New York City in December, 1906, a committee of seismology composed of fifteen members was appointed, and at a meeting of this committee held in Washington almost upon the first anniversary of the great California earthquake, arrangements were made by which the United States Weather Bureau will make application to the next Congress for an appropriation to be used in inaugurating a co-ordinated series of earthquake stations well distributed throughout the country.

The great Indian earthquake of 1897 was the first macroseism upon the land to be studied both by co-ordinated distant stations and by geologists upon the ground.[1] The diagrams of the stations show that the waves traveled not only through but around the globe, thus furnishing a sort of parallel to the atmospheric wave started by the eruption of Krakatoa in 1883.

The seismograms of some earthquakes show more than one set of large waves, and these have been designated W_1, W_2, and W_3. The first mentioned appear to have reached the station by the nearest

[1] R. D. Oldham, "Report on the Great Earthquake of 12th June, 1897," *Memoirs of the Geological Survey of India,* Vol. XXIX (1899), chap. xv. The unfelt earthquake, pp. 227–56.

arcual route. The waves, W_2, are from the diminished amplitude, and the time of their arrival to be ascribed to vibrations transmitted in the opposite direction over the antipodes, while the waves W_3 are relatively feeble and the time of their arrival is about 3 hours, 31 minutes behind that of W_1, or that necessary for the waves of section 5 to make a complete circuit of the globe with a velocity of 3.3 kilometers per second. The seismogram of the Turkestan earthquake of August 2, 1902, indicates these waves W_2 and W_3 distinctly.[1] (see Plate IV).

Milne has recently drawn attention to the interesting fact that even in the case of lighter earthquakes, from which the energy is so dissipated that no record is obtained at the more distant stations, a distinct thickening of the lines from the pen of the instrument may be noted in the station located at the antipodes.[2] These "antipodean survivors" of the large waves in English home stations may be traced to earthquakes in New Zealand, and their survival at the antipodes only is to be ascribed to the cumulative effects of waves which converge from many great circle routes.

There is much that is yet only speculation regarding the nature of the waves registered by the new seismographs,[3] and some of the waves which have been indicated in the records of non-astatic pendulums have originated in the instruments themselves; but the value of the methods devised for locating the disturbed areas seems to have been established. This tendency of pendulums to vibrate in their natural period is now being corrected by automatic damping devices, with which a new epoch in the development of the science is opened.

In his paper above cited Milne has brought together the results already obtained in the location of macroseisms.[4] On the basis of 265 such quakes recorded between 1899 and 1903, twelve seismic regions have been located which are either beneath the ocean or include both sea and continental border. (See Figs. 1 and 3 of

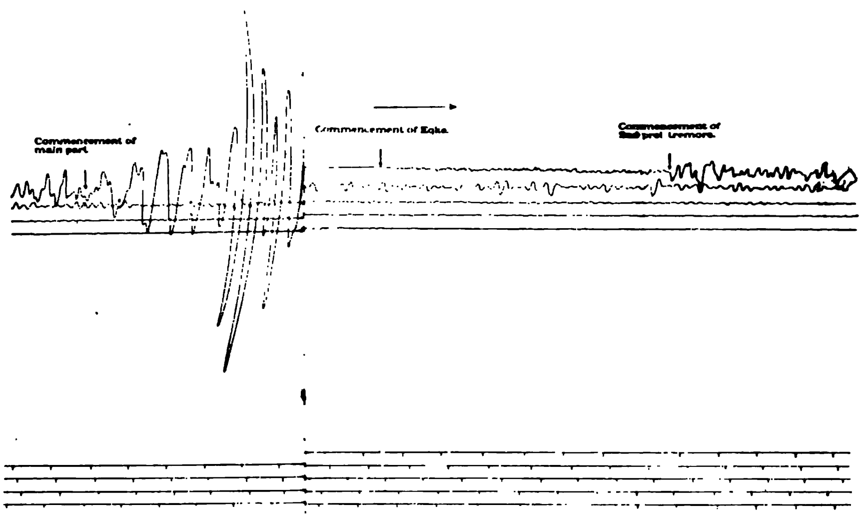
[1] Kikuchi, *loc. cit.*, p. 68, Fig. 37.

[2] John Milne, "Recent Advances in Seismology" (Bakerian lecture), ***Proceedings of the Royal Society***, Vol. LXXVII (1906), p. 373.

[3] See W. Schlüter, "Schwingungsart und Weg der Erdbebenwellen," ***Beiträge zur Geophysik***, Vol. V (1901), pp. 358, 359.

[4] A later report has been issued with 462 quakes included (Seismological Committee of the British Association for the Advancement of Science). See Fig. 2.

Plate IV


Commencement of main part
Commencement of Eqke.
Commencement of
prel. tremors.

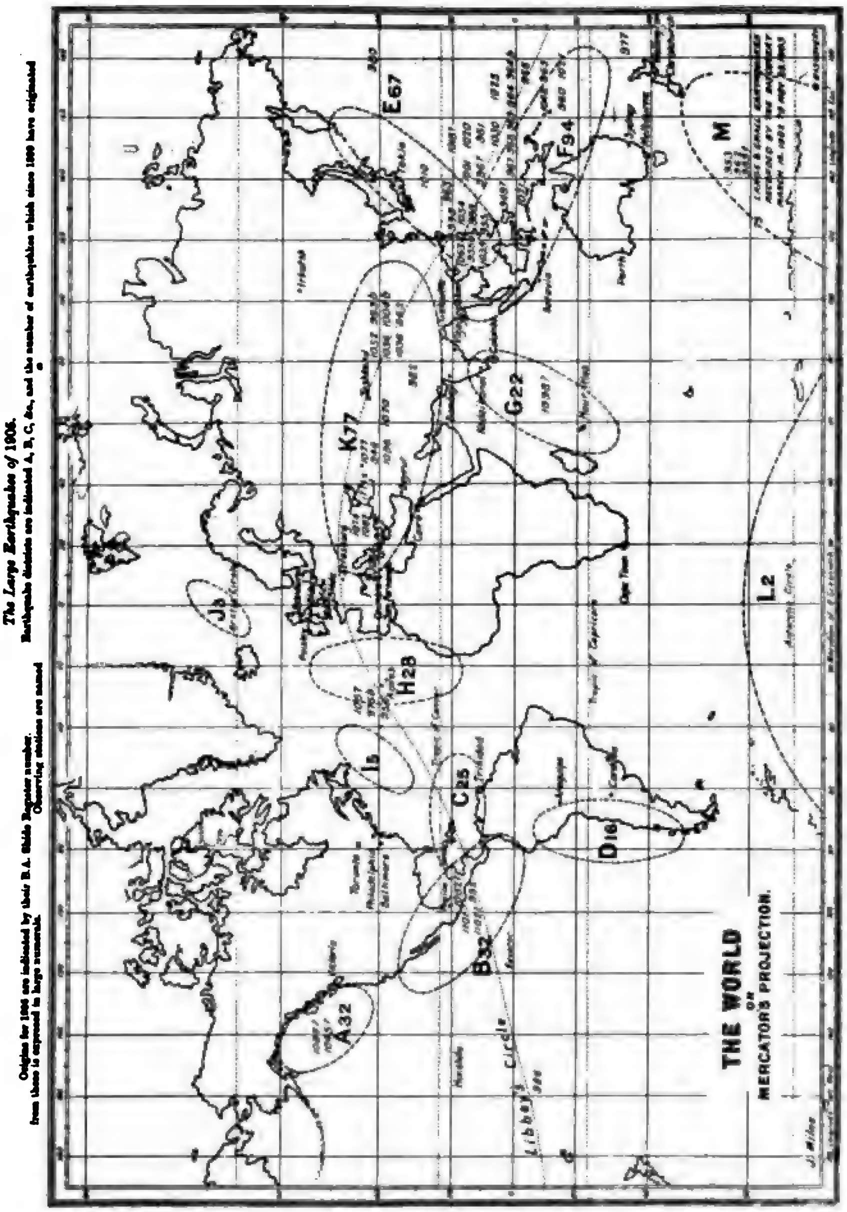


FIG. 2.—Map of earthquake "ovals," including the year 1905. (After Milne.)

the first paper of this series.) For the most part these are well-known earthquake regions, though the results have been criticized on the ground that certain well-known seismic regions, such as California, Andalusia, Lake Baikal, and New Zealand, are not indicated, while Newfoundland and the Indian Ocean are. As regards this objection, it should not be overlooked that regions of high seismicity may not necessarily be regions of equally frequent macroseisms, and the brief period that the method has been in operation removes much of the force of the objection so far as the seismic regions not indicated are cencerned. As regards Newfoundland, the "oval" of Milne merely grazes its corner and is centered over the steep wall of the ocean deep at the margin of the Great Banks. As this scarp is off the lane of transatlantic steamers, direct observation of submarine quakes should in any case be seldom made. We find, however that on September 27, 1838, the ship "La Claudine," Captain Blount, while in this vicinity (Lat. 31° 40′ N. and Long. 42° 10′ W.) experienced a most severe series of shocks which lasted three-quarters of an hour. Occurring in the night and in perfectly clear weather, everyone was aroused and rushed on deck believing the ship was going down. Nearly all the breaks in the Atlantic cables occur at this wall, and on October 4, 1884, the three cables running here in parallel lines, about ten miles apart, were simultaneously fractured at points opposite each other and in a straight line.

The other oval of macroseismic origins to which objection has been made is likewise seldom crossed by vessels except at its margins, but we have here the record that on October 13, 1863, a submarine quaking of great intensity, accompanied by rumbling like thunder, was felt by a vessel in Lat. 20° S. and Long 67° E. Other severe quakes have been felt by vessels near the margin of this oval on February 9, 1823, and on January 29, 1882. It seems likely, therefore, that the new method is extending our knowledge of earthquakes into regions of which we should otherwise have at best but little knowledge, and it confirms the generalization that much the greater number of movements within the crust occur beneath the sea and at the borders of the great ocean deeps. A map based upon a larger series of observations is reproduced after Milne in Fig. 2.[1] Milne's

[1] British Association, *Seventy-sixth Report* (York, 1906), Plate I.

earlier map displays in addition the ridges and deeps of the ocean floor, and he shows that there is a relationship between the distribution of origins of macroseisms and the pronounced irregularities of the relief; thus affording for the sea areas a complementary verification of de Montessus' conclusions.

EDITORIAL

The transfer of the United States Geological Survey from one administration to another is a matter of wide interest at any time, and is perhaps more than usually so at the present stage of official evolution in this country. The latter part of the administration of Major Powell and all of that of Dr. Walcott were conditioned by attempts to develop the related interests of irrigation, forestry, and so forth, and no small part of the time and strength of these administrations was given to enterprises very worthy in themselves, but not strictly geological. The Survey will have contributed much to the general good of the country by aiding in putting these related interests under scientific control, but, in the judgment of many geologists, the Survey itself has temporarily suffered in consequence, scientifically and probably financially. In the closing stages of Dr. Walcott's administration the chief of these annexations to the Survey were separated from it and the way prepared for a more strictly geological administration. Some further limitations may be wholesome, but the new administration under Dr. Smith inherits an excellent opportunity to show what can be done by an undivided devotion to the development of strictly geological work in the interest of industry, education, and science.

Just at present the attention of the country is specially alert to the future relations of federal and state functions, and this adds piquancy to the problem of the relations of the national to the state surveys. It is a hopeful sign that steps have already been taken to adjust these relations in a more satisfactory way. More fundamental than the formal relations of the national to the state surveys is the question of true interstate work with a view to general correlation and fundamental science, in contradistinction to essentially local work of an intra-state nature.

Of similar import is the question of the relations of the national survey to the institutions which produce its working talent. Of like importance is the obligation of the Survey to develop the talent it

employs by continuous work in broad, unrestricted fields, until real mastery is attained. Even more imperative is adequate provision for the close scientific oversight of each chief line of work by commanding talent, developed by a far-seeing and steadfast policy in the interests of the highest class of work.

These are only some of the large outstanding problems that give a rare opportunity to the new administration. In the solution of these, as also in the more mechanical as well as the more diplomatic problems of the Survey, Dr. Smith will have the cordial good wishes of geologists generally, and, beyond question, their help, if he chooses to draw about himself the united talent of the country.

T. C. C.

Geological surveys have recently been established in Arkansas and Colorado by the action of the legislatures of those states. Notable additions have also been made to the financial resources of the surveys of Illinois, Missouri, and Iowa. Some further favorable action is expected from legislatures still in session. In line with this there has recently been a notable increase in the facilities for geological instruction given in several of the higher institutions of learning in the same region. These correlative actions appear to indicate a marked growth of geological interest in the interior states. Co-operation between the state surveys mutually, and between these and the higher institutions of learning, has grown co-ordinately, and is a hopeful sign of further growth and strength in the future.

T. C. C.

REVIEWS

Maryland Geological Survey—Pliocene and Pleistocene. WILLIAM BULLOCK CLARK, State Geologist, 1906. Pp. 285, 13 figs., 75 plates.

This is the third volume of a series of reports dealing with the systematic geology and paleontology of Maryland. It consists of two parts; the first, devoted to the Pliocene and Pleistocene deposits of Maryland, by G. B. Shattuck, with interpretations of the paleontological criteria by W. B. Clark, Arthur Hollick, and F. A. Lucas; the second, to the systematic paleontology of the Pleistocene, by Clarke, Lucas, Hay, Hollick, Sellards, and Ulrich. The report appears in the handsome dress for which the Maryland reports have become noted, and its many and excellent illustrations give it an attractive appearance.

The chief geological contribution is Dr. Shattuck's report of 136 pages. Besides introductory matter, this treats of four formations: the Lafayette, regarded as Pliocene, and the Sunderland, Wicomico, and Talbot, regarded as Pleistocene. The last three are relatively new terms introduced by Dr. Shattuck to designate the Pleistocene formations which he discriminates. They cover in a general way about the range of deposits embraced under the Columbia of McGee. All these formations, including the Lafayette, are regarded as sea deposits, in the main, and maps are given showing the supposed extent of the Lafayette, Sunderland, Wicomico, and Talbot seas. The formations are conceived to constitute a succession of terraces which are said to be limited by sea-cliffs. The assigned relations of these terraces are made clear by a series of ideal diagrams. There is a notable similarity in the structure and constitution of these formations as indicated by the descriptions and the photographs, all consisting mainly of clay, loam, sand, and gravel, with iron ore and other segregations. A significant feature is the imperfect assortment and the irregular arrangement of the material, which affects particularly the upper parts of the formations.

The surface movements supposed to be involved in the formation of this series of deposits are summarized as follows:

Subsidence and deposition of the Lafayette formation.
Elevation and erosion.
Subsidence and deposition of the Sunderland formation.

Elevation and erosion.
Subsidence and deposition of the Wicomico formation.
Elevation and erosion.
Subsidence and deposition of the Talbot formation.
Elevation and erosion.
Partial subsidence and deposition of the recent terrace.

Dr. Shattuck closes his report with the remark that "a study of the Coastal Plain deposits from the bottom to the top shows that the Atlantic sea-board has been repeatedly elevated when loaded and depressed when lightened. It would seem that some other theory than that of isostasy must be proposed for these movements" (p. 137).

Under the head of interpretation of the paleontological criteria, Dr. Clark remarks that all the fossils come from the Pleistocene, none from the Pliocene, i. e., the Lafayette. Fossil plants are found in all three of the Pleistocene formations—though imperfect in Wicomico—but the animal remains are confined to the latest or Talbot formation. In addition to the marine fossils in the Talbot formation, leaves, seeds, fruits, twigs, branches, logs, and stumps are preserved, some of which, according to Dr. Hollick, represent the accumulation of vegetation in place, in swamps, lagoons, or estuaries, and some represent transportation from adjacent localities. A few mastodons' teeth and other vertebrate remains have been found in the Talbot formation.

One cannot quite agree with Dr. Clark in saying that "the evidence of the fossils, as far as available, bears out the conclusions" previously set forth (p. 139), if by that is meant the marine origin of the Sunderland and Lafayette formations, as one would infer. The occurrence of marine fossils in some parts of the Talbot formation, the lowland, sea-border member of the Pleistocene deposits, rising from 10 to 45 feet above sea-level, while land vertebrates and plants are found in other portions, implies that the deposit was formed partly under marine conditions and partly under terrestrial.

The occurrence of a score of species of land plants and the absence of marine fossils in the Sunderland formation, which lies at higher levels, point as distinctly, so far as the evidence goes, to the terrestrial deposition of that formation. The absence of fossils in the Lafayette of Maryland, and the presence of land fossils in the Lafayette elsewhere, point in the same direction.

Concordantly with the fossil evidence, geologists critically familiar with the distinctions between marine and terrestrial formations will be disposed to question the marine character of such kinds of assortment and such

structures as are shown in the several excellent photographs of sections of the upland formations. This questioning would be more pointed, if the chemical and physical state of these deposits had been more critically described. Question will also arise whether the little bluffs called sea-cliffs are really such. They look much like the terrace edges cut by low-gradient drainage. The digitate borders of the formations as mapped on Plate I, and on the restorations of the sea limits of the several stages as mapped on Plates XXVII–XXX, present strange alignments for the putative shores of the Atlantic. The little off-shore islands of soft material seem equally strange features. So also one looks in vain for the great sand-bars and strong beach deposits that are usually associated with ocean borders. If critical inquiry is turned to the elevations of the several parts of the upland formations, there appears to be a closer resemblance to the habitual hypsometry of terrestrial formations than to that of marine. One does not find in the report evidence of a clear perception of the methods of terrestrial deposition, such as are applicable to a region of this kind, and one is left with the suggestion that, when the region is critically studied with terrestrial criteria sharply in mind, the upland formations will be found to be typical terrestrial deposits, as implied by the fossil evidence. A part of the lowland Pleistocene is undoubtedly marine.

The systematic treatment of the paleontology of the Pleistocene deposits is an admirable feature, and will prove very serviceable in the study of the Pleistocene formations of the coast both to the southward and to the northward where warmer and colder faunas, respectively, were prevalent.

T. C. C.

THE

JOURNAL OF GEOLOGY

JULY–AUGUST, 1907

GLACIAL FEATURES OF THE ALASKAN COAST BETWEEN YAKUTAT BAY AND THE ALSEK RIVER[1]

ELIOT BLACKWELDER
University of Wisconsin

Since the pioneer studies of Russell, Reid, and Muir among the glaciers of southern Alaska, the extension of exploration has gradually brought more and more of them within the range of observation, until now most of the more important have been located and a few of them carefully described. The ice-fields of the St. Elias region are among the most interesting of these, and, thanks to the researches of Russell, Gilbert, Tarr, and Martin, are among the best known. It was my privilege in 1906 to explore portions of the coast immediately east of the field studied by these men. The present paper is presented in order to record for the first time[2] the glacial features of that strip, and to form the basis for the further exploration and comparative study which is sure to come in later years.

From Yakutat Bay to the Alsek River the outer coastal mountains, for which I propose the name Brabazon Range,[3] is separated from the

[1] Published by permission of the Director of the U. S. Geological Survey.

The accompanying map has been redrawn and adapted from the field map prepared in 1906 by my associate in the field, Mr. A. G. Maddren. Certain additions are based on photographs and surveys by Mr. A. J. Brabazon, of the Canadian Boundary Survey.

[2] Previous maps show the position of the larger glaciers, but no description of them has been given.

[3] From A. J. Brabazon, of the Canadian Boundary Survey, who in 1895 made the first topographic map of these mountains. The range begins at the lowest

Pacific by an alluvial coastal plain. On the east side of Yakutat Bay low morainic deposits, densely wooded, slightly relieve the general flatness, and along the mountain front low rocky knobs rise to a height of 100 feet or more. Aside from these exceptions, the plain has the monotony of a delta surface. Much of it is covered with dense spruce forests; but wide tracts are kept bare by the floods[1] of such rivers as the Dangerous and the Alsek, and by the tides, as at the mouth of the Italio; while swamps and wet mossy prairies occupy large irregular areas farther inland.

The Brabazon Range is low as compared with the lofty peaks west of it; but nevertheless it is a notable feature of the coast. It has a steep seaward front, which, although somewhat irregular in outline, plunges abruptly beneath the alluvial flat without extensive foothills or projecting spurs. One depression interrupts the continuity of the ridge in the area discussed—the open channel of the Yakutat Glacier. The highest peaks of this range are Mount Unana (6,000 feet) and Mount Ruhamah (5,600 feet[2]) on the east side of Russell Fiord, together with Mount Reaburn[3] (5,300 feet) and its nameless neighbors east of the Yakutat Glacier. Within the mountains the topography is buried under a thick mantle of ice, through which isolated mountains protrude—"a land of nunataks," as Russell has aptly described the country about Mount Logan.

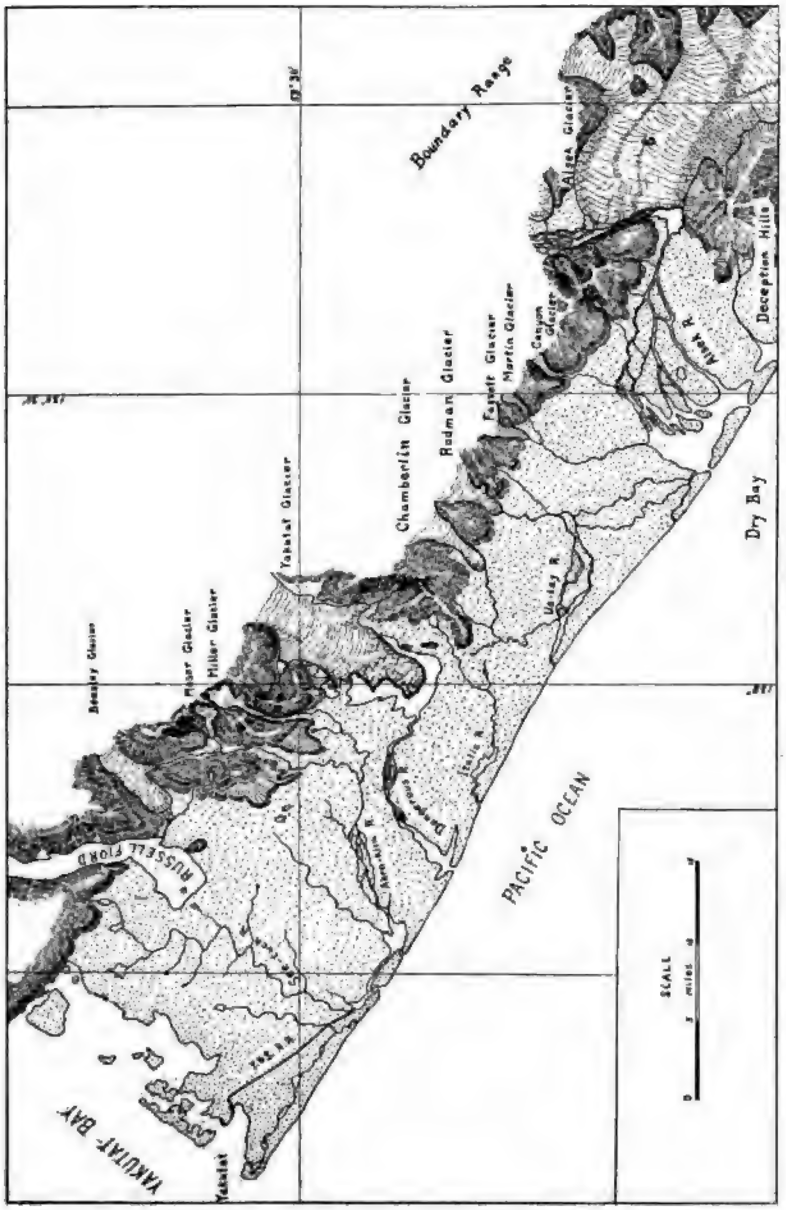
The only large river of the region is the Alsek—a powerful stream which rises in the plateau north of the mountainous belt and trenches the uplift in a series of wild canyons which have a total length of

canyon of the Alsek River and fronts the foreland northwest as far as Russell Fiord. It is separated from the inner ranges largely and perhaps wholly by broad ice-fields. Structurally it seems to be continuous with the Puget peninsula on the northwest and Deception Hills on the southeast, but it is separated from them by the fiord and river mentioned.

[1] For an example of similar devastation by the Yatse River, see Russell "Second Expedition to Mt. St. Elias," U. S. Geological Survey, ***Annual Report*, *XIII***, p. 60.

[2] Elevations taken from maps of the Canada-Alaska Boundary Award (based on Brabazon's survey of 1895).

[3] This peak is named in honor of Mr. W. B. Reaburn, who, as a member of the U.S. Boundary Survey Party in 1906, was the first white man to cross the Yakutat Glacier, from the surface of which this peak is a conspicuous landmark. The mountain is situated approximately in latitude 59° 26½′ north and longitude 138° 38½′ west, and is the first high peak east of the Yakutat Glacier. (See Fig. 3.)



Map of Alaskan coast between Yakutat Bay and the Alsek River The dotted area is the coastal plain; the larger glaciers are shown by the broken lines, with moraines dotted, while the little cliff-glaciers are represented by the black.

about 110 miles. Majestic glaciers descend into it at several points on either side, contributing their load of detritus to its turbid current. Eventually it emerges from its canyon through the outermost or Brabazon range and spreads out in shifting channels over a broad, gravelly delta. At the time of our visit there were three main distributaries at the head of the delta, which anastomose with each other to some extent below. An abandoned moraine of the Alsek Glacier checks the river temporarily as it leaves the canyon, and thus forms a small but deep lake at the elbow of the sharp bend. Icebergs of all sizes are constantly breaking off from the end of the glacier. Some lie stranded on the shelving shores of the lake, while others gradually drift into the current of the outlet and are thence whirled out upon the delta. All melt before reaching the Pacific.

The coastal mountains of this part of Alaska are still, like Greenland, in their glacial period. All the principal valleys are clogged with ice, and only the smaller gulches are without glaciers. The glaciers vary in size from mere snow-fields which have a slight motion, to great plateaus of ice, scores of square miles in extent. The front of the Brabazon Range affords eight or nine glaciers of considerable size, in addition to the Alsek Glacier which lies to the west, and the numerous little cliff-glaciers which are found in the lateral ravines. Some of these larger lobes we observed only from a distance, but others were examined in some detail.

We may now take up the consideration of the several glaciers individually, beginning where Russell and his successors left the work, and carrying the chain with varying detail as far as the Alsek. The first in order is the Beasley Glacier,[1] a lobe which joins the sources of the Hidden Glacier across a snow-filled pass and thence descends southwestward on the east side of Russell Fiord. This we saw only from the mountain spur east of it. Its clear white surface is striped with two or more distinct moraines. Sloping gradually downward, it ends in a barren outwash-flat composed of gravel and bowlders.

[1] This glacier is generally known to the people of Yakutat as the "Fourth Glacier," but as there is no logical starting-point in enumerating the glaciers by number in such a way as to make this the fourth, it seems advisable to give this large and conspicuous lobe a definite name. For this reason, it is proposed to call it the "Beasley Glacier," in recognition of the valuable services which have been rendered to every explorer, who has visited the Yakutat region since the eighties, by Mr. R. W. Beasley, of Yakutat.

FIG. 1.—Terminus of the Moser Glacier, with snow-bank glaciers upon the slopes behind. Taken from the crest of the moraine.

The water discharged issues in several streams, but these combine in a recent cut through the encircling morainic ridge and reach the fiord as a single river.

. The Moser valley contains two considerable tongues of ice and several little cliff-glaciers. At the extreme head of the valley a short triangular lobe overflows from the adjacent Beasley Glacier, while a somewhat larger glacier occupies the tributary canyon which joins the main valley from the eastward. The latter we take to be the Moser Glacier.[1]

The triangular lobe from the Beasley Glacier is smooth and white. At its terminus there is no distinct moraine, nor is there any considerable amount of débris upon the end of the ice itself. A level outwash train of coarse gravel trends away from the glacier down the valley.

The Moser is an excellent example of the small alpine glacier. If its snow-fields are included, it is about 2½ miles long, the bare icy portion being about 1½ miles in length. The width of the cirque is nearly 1½ miles, but the glacier itself has a constant width of slightly less than half a mile. It lies in a deep canyon, the walls of which rise steeply to heights of 1,500–2,000 feet, and then more gently to summits about 2,000 feet higher. The cirque is filled with snow and névé which is slightly crevassed. Lower down the transverse crevasses become much more numerous and the clear ice makes its appearance. About a mile from the lower end, the angle of slope becomes much gentler, the crevasses less numerous and radial rather than transverse in direction, and the surface is comparatively smooth. At the time of our visit it was not difficult to cross the lower part of the glacier in almost any direction, provided one paid due regard to the many, although narrow, cracks. On each side of the lower end of the tongue the ice is covered with débris which stands out upon the surface in relief, forming two lateral moraines. A medial moraine makes its appearance suddenly three-tenths of a mile from the end, and is a prominent feature of the nose of the glacier. Its origin is not obvious. At no distant time the Moser Glacier has been three-

[1] Lieutenant Hugh Rodman, of the U. S. Fish Commission, passing along the front of the foreland in 1901, observed that this valley contained a glacier, and, supposing doubtless that it was a single tongue of ice, he named it the Moser Glacier. In 1906 we found two distinct glaciers in this valley, and have applied to the larger of them the name proposed by Lieutenant Rodman.

tenths of a mile longer than at present, and simultaneously probably several hundred feet thicker. This expansion is clearly recorded by a bowldery moraine which encircles the mouth of the canyon and is attached to the rocky walls on either side by a gradually diminishing lateral moraine, or moraine-terrace, which now stands at a considerable elevation above the glacier. The abandoned space inside the moraine is a bowldery waste devoid of vegetation. The outer part of the moraine itself, however, is forested with spruce, and its hummocky topography is thereby obscured.

The little cliff-glaciers of this valley which have been mentioned are of various sizes and are about four in number. Three of these occupy the southern slope of Crescent Mountain.[1] They are steep, cascading glaciers which are plastered in the heads of the shallow gulches. The fourth, which lies upon a gentler slope south of the Moser Glacier, is irregular and roundish in outline. It is noteworthy that no glaciers exist on the northeast slope of Slate Peak.[2]

The next valley to the eastward, drained by another branch of the Ahrn-klin River, contains one glacial lobe and several little snow-bank glaciers. Its cirque affords an ample gathering ground for snow, and is separated from the head of the Moser Glacier on the west by a sharp arrete. The tongue of ice itself is somewhat longer and narrower than its neighbor, being about 2¼ miles long and about one-fourth of a mile wide. The lower end is black with moraine-stuff, and frequent avalanches from the steep walls of the canyon keep the sides dirty with similar débris.

The Miller Glacier appears to have a surface much like that of its western neighbor, but even less crevassed. It shows no evidence of recent advance and is not surrounded by a distinct moraine. Miller Creek issues from the end of the glacier and flows over a barren, gravelly valley-train out to the foreland.

The little cliff-glaciers of this canyon are few in number. We noted but one on the west side of the valley, and that at an elevation of 3,000 feet. On the east side three or four little bodies of ice occupy hollows in the lee of the mountain crest.

[1] So named from the crescent-shaped syncline of gray rock visible in its summit. It lies immediately north of the Moser Glacier.

[2] In 1906 Mr. Thomas Riggs, Jr., applied this name to the peak which separates the Beasley Glacier from the Moser valley.

The open gap which interrupts the Brabazon Range midway in its course is partially filled by the broad Yakutat Glacier. This is merely a lobe descending from the interior ice-fields, not an alpine glacier of the type illustrated by the Moser and Miller lobes. The descent of the Yakutat Glacier is gradual throughout, but at several places there are steeper declivities, more crevassed, which approach the character of ice-falls. The length of the glacier after it leaves the parent ice-field appears to be about 12 miles. Its average width is

FIG. 2.—The Miller Glacier. A short alpine glacier descending from the snows of a capacious cirque.

3–4 miles, but toward the end it becomes ragged in outline, and the width decreases to 2½ and finally to 1½ miles. So far as observed, the surface of the ice is badly crevassed, especially near the terminus. There the ice is broken by great cracks, some of which admit the water of the lake far back into the glacier. Four or 5 miles back from the end, and especially along the margins of the glacier, there are, however, certain stretches which are moderately smooth and may be traversed without notable difficulty. The Yakutat Glacier lacks the prominent

FIG. 3.—Surface of the Yakutat Glacier. On the left is the gap in the range through which the lobe finds exit from the inner ice-fields. The snowy cloud-wrapped peak to the right of the center is Mount Reaburn.

trains of débris which lie upon the surface of almost all the other glaciers of the region.

The lower end of the glacier is encircled from mountain to mountain by a crescent-shaped moraine more than a mile wide, which rises but a few score feet above the foreland. It has the characteristic knob-and-kettle topography of terminal moraines in general, contains numerous small lakes and swamps, and is strewn with bowlders. The till consists largely of rocks of the Yakutat series (early Mesozoic ?), with the addition of many crystalline schists and intrusives from the older formations. One of the most conspicuous varieties represented in the large bowlders on the moraine is the coarse graywacke-conglomerate of the upper portion of the Yakutat series.[1]

Between the inner edge of the moraine and the ragged border of the glacier lies a long, irregular lake, to which we have given the name Harlequin Lake.[2] The water is muddy with the rock-flour derived from the glacier. Occasionally during the day the crash of icebergs falling into the water may be heard, but disintegration here is much slower than it is along the front of the Alsek Glacier. The water of the lake is now discharged through a cut in the moraine and makes the Dangerous River. On the borders of the lake and the surface of the moraine there is evidence that the lake waters have recently been much higher than at present, and that they have not always used the same exit as at present. A series of well-marked and unmutilated wave-built terraces encircles the lake on the moraine side at various elevations up to 100 feet above the present surface of the water. About a mile north of the present Dangerous River the moraine is intrenched by two dry outlet channels, which converge and join before reaching the outer edge of the moraine, so that they issue in a single channel. The channels are bare and strewn with gravel and bowlders. They are from 60 to 100 feet deep, and the bottoms

[1] The outer front of the moraine is bordered by an extensive outwash-plain. Near the foothills on the west this plain slants perceptibly outward from the moraine, while nearer the Dangerous River the declivity is hardly perceptible. Shallow dry channels furrow the outwash at several places. Near the moraine the normal flood-plain of the Dangerous River is about 30 feet below the plain, but 5 miles nearer the ocean the difference is scarcely 5 feet.

[2] Named from the fact that a pair of harlequin ducks were the only living things seen upon it.

were about 40–50 feet above the surface of the lake in 1906. The fact that vegetation has not invaded these channels suggests that they are of very recent origin, and this inference is borne out by the freshness of the loose terraces bordering the lake. It is suggested that the Dangerous River outlet may at times become so clogged with icebergs as to form a dam, and that the level of the lake is therefore subject to fluctuations. This may perhaps explain the reputation for disastrous floods which the river has among the natives of the Yakutat

FIG. 4.—Shattered side-lobe of the Yakutat Glacier. Shows the scarp and the mass of freshly broken ice which resulted from the collapse in 1906.

foreland; for the breaking of such an ice-dam would liberate suddenly a large volume of water.

Tributary valleys coming in from the southeast and northwest have been obstructed by the glaciers, and thus several marginal lakelets have been produced. On the west side of the glacier we observed at least four of these blockaded lakes. The uppermost and largest one was found completely filled with a mass of clear broken ice and held in by a much-crevassed scarp of ice about 200 feet high.

Evidently the lake was formerly covered by a glacial lobe which has since collapsed. The extreme recency of the occurrence is indicated by the fact that many blocks of ice lie stranded upon the rocky sides of the valley 50–100 feet above the water, thus marking the original level of the glacier. As such detached fragments usually melt quickly in the mild summer months, it can hardly be doubted that the collapse took place in 1906. The lowest of these lakes discharges its waters into the terminal lake through a cascading brook. The higher lakes, however, must have subglacial outlets; much water is poured into them by streams from the adjacent slopes, yet there is no exit for this upon the surface. It seems probable that the subsidence of the ice in the uppermost lake was caused by an unusually rapid removal of water through such a subglacial channel.

The Yakutat Glacier receives no considerable tributaries from the mountains on either hand. A few snow-fields and a few diminutive glaciers occupy the heads of the gulches on both sides, particularly in the valley which contains the shattered ice above mentioned, but these do not reach the bottoms of the valleys.

Of the glaciers between the Yakutat and the delta of the Alsek, as well as on the west side of the Yakutat Glacier itself, I can give only brief mention. Our route lay too far from the mountains to permit us to see them in detail. The Chamberlin, Rodman, and Fassett are all large alpine glaciers, and all extend out upon the edge of the foreland. On previous maps they are represented as being lobes of the inner ice-plateau, but the view from the foreland gave no confirmation of this. Although the upper reaches of the glaciers are hidden by the turnings of their canyons, and thus it is not possible to see directly whether they come through the rock divide, it is significant that they have steep descents, which are much more characteristic of the isolated valley glaciers than of the large "through" lobes.

Two smaller glaciers lie east of the Fassett. One, the Martin[1] Glacier, is a rather narrow tongue like the Miller and descends nearly to the level of the plain. Its companion on the east is of similar size, but does not descend as low. It derives its name from the fact that it is sunk deep in a canyon, the walls of which are remarkably

[1] After Mr. E. R. Martin, who was in immediate charge of the U. S. Boundary Survey Party which surveyed this portion of the range in 1906.

FIG. 5.—The Alsek Glacier as seen from the end of the Brabazon Range. The boundary range in the rear culminates in Mount Fairweather on the right. In the left middle is the Green Nunatak with its medial moraine. The extreme left of the glacier is not shown in the picture. The canyon of the Alsek River is hidden by the spur in the foreground. (Photo by Brabazon, Canadian Boundary Survey, 1906.)

precipitous and continuous. The lower end of the glacier is smooth and dirty with the débris of avalanches from the cliffs above. Doubtless the absence of notable crevasses here is to be ascribed to the fact that the ice is closely confined down to its very end, and hence the tension which would result from an unrestrained deployment is lacking.

From the Canyon Glacier east to the Alsek River no glaciers of considerable size remain. The heads of the gulches have been glaciated, as is indicated by the well-developed cirques and the rock-bound lakes; but only very small snow-bank ice-fields now remain.

The Alsek Glacier is the largest of all in the area of our survey. It heads on the west slope of Mount Fairweather, and, after receiving many icy tributaries from the Boundary Range north of it, eventually reaches and constricts the Alsek River at its lowermost canyon. The lower part of the glacier is a great, flat ice-field or plateau having a breadth of 6–7 miles from northwest to southeast, and somewhat more from northeast to southwest. The main body of the glacier comes in from the east just behind the Deception Hills. Two broad tributary tongues enter southeast of the Green Nunatak,[1] while a third, which is double, comes down from the boundary range some distance farther to the north. Each of these tributary glaciers would in most regions be considered large by itself. The influence of the great lobe from Mount Fairweather seems at present to be slight, as is evidenced by the fact that the south side is not bulged northward at the junction. Much of the ice is clean and white, but a number of medial and lateral trains of dirt blacken it in places. Apparently by the slow spreading of the glacier itself, these moraines have widened and even coalesced in their lower courses. Different parts of the glacier show wide variations in the amount of crevassing which they have suffered. In general, the steeper parts of the tributaries are much cracked. Of the open plateau-like expanse at the end, the northern part is not much crevassed, and its level surface may be traversed safely if ordinary care is used. The cleaner part, south of the Green Nunatak and Gateway Knob, is a bristling mass of sharp seracs with deep crevasses between. It would be very difficult, and

[1] This name is applied in recognition of the fact that the medial moraine which originates in this nunatak consists chiefly of green slate fragments.

FIG. 6.—The lowest canyon of the Alsek, from within. On the left are the Alsek Glacier and the Deception Hills; on the right, the inner slope of the Brabazon Range, with four of its many little glaciers. The overloaded Alsek in the foreground is a typical glacial river. (Photo by Brabazon, Canadian Boundary Survey, 1906.)

probably impossible, to cross this portion of the glacier without going far eastward to the foot of the mountains.

On the northwest border the glacier descends gradually to the alluvium which bounds it on that side. Where the glacier reaches the river itself it has a vertical front 4 miles in length, which is interrupted only by the rock hill (called Gateway Knob) at the mouth of the canyon. To the north of this hill there appears to be little movement in the glacier, as bergs drop off only infrequently.

FIG. 7.—Front of the Alsek Glacier. Dirty portion north of Gateway Knob, showing the horizontal stratification of the ice.

South of the rocky knob the front shows the beautiful blue-green color characteristic of freshly broken clean ice. Large masses of ice, usually the blocks between crevasses, break off from this front with thunderous crashes on an average of more than once an hour during the summer. The front itself is nearly 200 feet high, but even these huge masses of ice disappear completely beneath the water into which they fall, and then bob up from below and float away down the river. This indicates that the depth of water along the front is very great.

From the southern end of the frontal cliff a heavy deposit of moraine extends out in the form of a broken loop. The river is actively cutting into this deposit of till and seems to have destroyed a considerable part of it. The remainder forms a hook-shaped barrier on the south side of the river and sufficiently retards the current to form the Alsek Pool. This bulb-shaped expansion of the river at the mouth of the canyon is nearly 2 miles in diameter, and but for the gravelly plain on the north would be nearly square. On the north side of the

FIG. 8.—Front of the Alsek Glacier. Vertical cliff of dirty ice 160 feet high continually undermined by the river.

river the complement of the moraine ridge has not been identified. In spite of the powerful current poured into it by the Alsek the surface of this lake is nearly still. The bergs which fall from the glacial scarp drift very slowly down toward the exit from the lake. Sometimes they become stranded on the shallow north beach, where they are broken up by the waves and melt. At times those which succeed in reaching the exit congregate there in such masses that the channel becomes congested with them, and the river is temporarily

raised until sufficient force is accumulated to sweep out the obstruction. Sudden rises of as much as 6 feet, which we noted at the mouth of the canyon, are attributed to this condition.

Within the valley of the Alsek, above the lowest canyon, numerous glaciers of all sizes line the slopes on both sides. All the valleys are filled with huge lobes of ice. The smaller canyons have steep mountain glaciers, and scarcely a ravine in the higher mountains is without its little glacial tongue (Fig. 6). But this by itself is another story which is still too imperfectly known to be presented at this time.

Among the glaciers which have been described in the preceding pages we may readily distinguish four types. In the cirques and ravines high up in the mountains there are many little cliff-glaciers which are often no longer than wide, and are usually steeply inclined. The majority of them lie more than 2,500 feet above sea-level. In the larger canyons, valley-glaciers of the alpine type are found. These are tongues of ice usually several miles in length, fed by ample snows in the gathering grounds at their heads. The Miller and Canyon Glaciers are good examples. To another type, exemplified by the Yakutat and perhaps the Beasley, Tarr has applied the name "through glaciers,"[1] meaning the great lobes which protrude outward from the inner ice-plateau through gaps in the mountains. These are characteristic of the Yakutat-Alsek region, and are apparently numerous in the upper valley of the Alsek River. They are all large. The fourth type includes the great plateau-like sheets of ice which Russell has called "piedmont glaciers." They are fed by alpine glaciers from various directions and are among the largest glacial features of the region. The Alsek Glacier exemplifies this group.

One of the questions of interest with reference to all glaciers relates to their fluctuation in size. It is needless to say that, during the previous geologic epoch when all the glaciers of North America were greatly expanded, those of the Brabazon Range responded in the same way to the general causes of increase. Since that time they have retreated to fractions of their former lengths and have been reduced in thickness by 2,000 feet or less, according to their sizes and the con-

[1] Tarr and Martin, *Bulletin of the American Geographical Society*, XXXVIII (1906), p. 149.

figuration of their valleys. Changes within the past century are less well indicated.

The subject of glaciation should not be left without a statement regarding the recent changes in the glaciers. In this region no earlier measurements or surveys of sufficient accuracy have been made, and we are therefore without precise data. The fact that each of the glaciers examined is bordered at its end by a terminal moraine, which is separated from the ice itself by a barren space, indicates that the lobes have recently retreated through distances varying from one quarter of a mile to one mile. The Yakutat Glacier is bordered by a lake, and the end of the ice is so badly broken as to give one the impression that it is disintegrating in a condition of relative stagnation. It is obvious at least that none of these glaciers is now actively forwarding its lower end. In no case did we find glaciers plowing up forested moraines and showing other unmistakable signs of advance, such as Tarr reports of the Malaspina.[1] It will be a matter of much interest to watch these glaciers east of Yakutat Bay, and see if they follow the example of the St. Elias lobes, or whether they evince no sympathy with them. This will go far toward solving the question as to whether the advance of the Malaspina is due to a local cause or to some general climatic influence.

[1] R. S. Tarr, *Science*, N. S., Vol. XXV (1907), pp. 34–37.

STRATIGRAPHY AND STRUCTURE OF THE PARK CITY MINING DISTRICT, UTAH[1]

J. M. BOUTWELL

CONTENTS

INTRODUCTION

The Central Wasatch supplied evidence for important principles to the pioneer geologists, and valuable data to succeeding investigators, and now, in the light of recent detailed studies, is proving to be a most fruitful geologic field. It was thus the source for epoch-making writings on orogeny by King and Emmons; for significant observations on the relations of certain igneous masses to sediments by Geikie; for the determination of striking facts of pleistocene geologic history by Gilbert; and for important contributions by other geologists.

The first detailed geologic mapping in this historic region was undertaken in August, 1902, in connection with an investigation of the geology and ore deposits of the Park City Mining District. This was continued through the field season of 1903 and completed in 1904. As a necessary preliminary, broad comparative studies of the geology of the range north and south of the immediate area under survey were made, and standard sections, notably one which was unusually well

[1] Published by permission of the Director of the U. S. Geological Survey.

exposed in Big Cottonwood Canyon, were carefully measured and critically studied. Among the results secured is the precise definition of several stratigraphic formations, including one carrying a previously undescribed Permian fauna; also the solution of several faults of large offset which bear significantly upon mining operations.

Three brief progress reports have been published. The complete statement of the results of that investigation will go to press this year in the form of a "Professional Paper" of the United States Geological Survey. It seems desirable, however, that certain results should be made public at once. This paper has therefore been prepared by request for the purpose of introducing the names of certain stratigraphic formations for the use of writers on these formations in adjacent regions, and of rendering the broad, structural results of the work available for use by local operators.

In this connection it is a pleasure to acknowledge the valuable contributions toward these final conclusions. Thus, the investigation has throughout been under the general supervision of Mr. S. F. Emmons, and in the first year was carried on jointly by Dr. J. D. Irving and the writer, and during the remaining two years benefited by the service of Mr. L. H. Woolsey. Dr. T. W. Stanton has identified the fossil collections from the Jurassic and Triassic, and also in 1903 kindly co-operated in the field in the solution of special problems of stratigraphic correlation; while Dr. G. H. Girty has determined the fossil collections from the Carboniferous, numbering over 100 distinct lots, and throughout the investigation has given helpful interpretations of paleontological evidence. The writer began his work in the region in October, 1900, when it was his good fortune to discover material proof that the main Little Cottonwood granite mass is intrusive in quartzite of Cambrian age, and that the Alta granodiorite body is intrusive in limestone of Pennsylvanian age.[1] In addition to the detailed study of the immediate Park City District throughout the period of survey, he has also carried on comparative studies in stratigraphic correlation and general geology in adjoining portions of this range and the Uintas.

[1] S. F. Emmons, "Little Cottonwood Granite Body of the Wasatch Mountains," *American Journal of Science*, Vol. XVI (August, 1903), pp. 139–47. J. M. Boutwell, "Progress Report on Park City District, Contributions to Economic Geology 1902," U. S. Geological Survey, *Bulletin, No. 213* (March, 1903), p. 36.

GENERAL GEOGRAPHY

The Wasatch Mountains, in their middle course, lie in the eastern part of Utah. They are a lofty, rugged range trending northerly and southerly between the Great Basin on the west and the mountainous plateau regions on the east. From a ragged serrate divide on sharp, ledgy peaks 10,000 to 11,000 feet high, the western slopes fall off abruptly 5,000 to 6,000 feet by a wall-like front of striking steepness to the desert below; while the eastern slope, in marked contrast, gives way gradually to upland ranges, plateaus, and high-lying meadows. This unsymmetrical range may thus be compared to a mammoth step several thousand feet in height from the Great Basin on the west to the highlands which extend from its upward portion eastward. These western slopes are interrupted by deep, narrow, rock-walled canyons, through which the drainage from the uplands and parks escapes westward to the desert. The portions of the western wall which lie between these canyons show a marked type of dissection which is characterized by ravines that rise from the level of the desert with steep sides and bottoms, and fork symmetrically upstream repeatedly. The topography in both its larger and smaller features, showing rugged, precipitous slopes, deep, narrow canyons with ungraded bottoms and side cataracts, is indicative of the youth of this range.

GENERAL GEOLOGY

The rocks which form the range are sedimentary, metamorphic, and igneous. The Wasatch sediments, as concisely described by King,[1] are made up of four great divisions, a purely detrital series of Cambrian age, a great limestone extending from Cambrian to the top of the lower Coal Measures, a body of pure siliceous detritus of upper Carboniferous age, and a fourth body of limestone of upper Coal Measure age. The metamorphic rocks include the early regionally metamorphosed sediments and the locally altered or contact metamorphosed rocks. Beyond the fact that these great metamorphic series are pre-Cambrian, their age is unproved, though they are known to be the oldest rocks in the Wasatch. The igneous rocks include several large granitic and porphyritic intrusives and extensive flows.

[1] Clarence King, *Geological Exploration of the Fortieth Parallel Survey*, Vol. I, pp. 100, 101.

The ages and relationships of some of these masses have not yet been completely established.

Structurally the Wasatch Range is a composite, orographic unit. In the largest conception, it is a linear north-south anticlinal range, truncated on the west and probably south by great faults. This major structure is made up of four parts: (1) the Logan syncline, pitching north; (2) the eastern limb of an anticline, constituting the western rim of a Tertiary basin; (3) in the middle part (*a*) a narrow easterly-westerly syncline and (*b*) an easterly-westerly anticlinal dome; (4) to the south the eastern limb of a north-south syncline, probably truncated south of Mount Nebo by a great northeast-southwest fault, with the downthrow on the southeast. These larger structures are exceedingly complicated by several systems of intricate faulting.

The greatest geological activity in the Wasatch Range was in the middle portion at its junction with the great east-west Uinta Range. Extensive and irregular intrusion, widespread extrusion, thorough contact metamorphism, persistent and recurrent faulting, and glaciation have produced in a comparatively small area highly varied and complex geology. At the heart of the area in the focus of these combined factors have been formed the most extensive and richest ore bodies in the range.

This limited area, about 24 square miles, is known as the Park City District. It lies about 38 miles southeast from Salt Lake City, and embraces in its southwest corner the main divide of the Wasatch (Clayton Peak, 10,728 feet), and a prominent spur descending eastward 4 to 5 miles to high-lying interior valleys. The spur separates the area into three natural topographic divisions, which accord with the rock and structural divisions—namely, the north and northwestern slopes, the eastern slopes, and the southern. In the northern and northwestern portions the complete sedimentary sequence is present, dipping universally to the northwest at a moderate angle. On the eastern slope the same formations occur (with noteworthy variations), dipping in general easterly, much faulted, and intruded by irregular stocks and dikes, and on the northeast partly buried by an extrusive mass. The southern portion embraces the great laccolithic stock of diorite in Clayton Peak on the southwest; dikes and stocks of andesite porphyry cutting upward into the overlying sedimentary formations;

and a great east-west zone of contact metamorphosed sediments. It is these metamorphosed rocks which thus hardened stand up as the backbone of the region, the divide between north and south drainage, and form the home of all the great bonanza ore bodies of the district.

STRATIGRAPHY

GENERAL DESCRIPTION

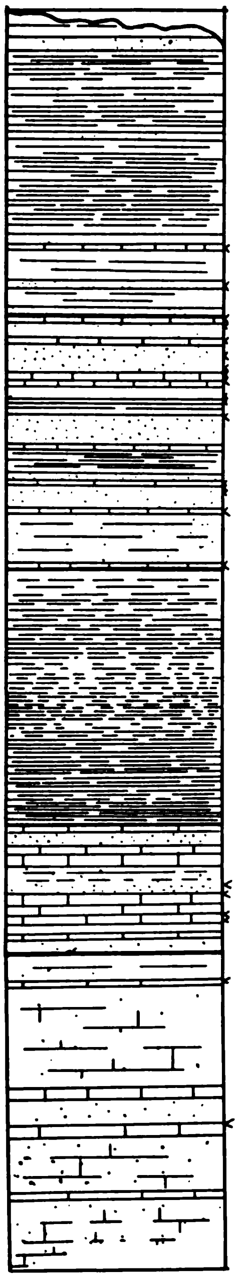
The sedimentary rocks within this district are of Carboniferous and Triassic ages. They are divisible on paleontologic and lithologic evidence into five formations. The lowest (oldest) comprises the upper part of the Weber quartzite, which yields a Pennsylvanian (upper Carboniferous) fauna. Overlying this quartzite is the Park City formation of limestone and sandstone, the former bearing Pennsylvanian fossils. Next above is the unfossiliferous Woodside shale, which is succeeded by the Thaynes formation. The limestones in this formation yield a new fauna resembling both Carboniferous and Permian, considered of "Permian age." The highest beds in the district are the unfossiliferous shales constituting the lower part of the formation which passes upward a few miles northwest of this area into the Triassic sandstone, and thence into the Jurassic limestone.

WEBER QUARTZITE

Name.—About 30 miles due north from Park City and 1 or 2 miles west from Croydon station, the great gray quartzite of the Wasatch section forms both walls of Weber Canyon. "It is from the characteristic occurrence of this remarkable bed of quartzite that the name 'Weber quartzite' has been given to the body" by the geologists of the Fortieth Parallel Survey.[1]

Critical paleontologic and stratigraphic studies lead to the conclusion that the great quartzite of the Park City district is the stratigraphic equivalent of the Weber quartzite in Weber Canyon. Accordingly the name "Weber" will be extended to apply to this formation in the Park City district. Locally it has been known, after the famous mine which lies in it, as the "Ontario" quartzite.

[1] Clarence King, *Geological Exploration of the Fortieth Parallel Survey*, Vol. I, p. 161.



Character Fossil bearing horizons	Thickness	Formation		
Red shales—locally sandy—with interbedded coarse gray sandstones. Carries, in lower portion *Aviculipecten Weberensis*, *A. curticardinalis*, *A. parvulus*, *Myalina permiana*. No economic importance.	1.500+ feet	Ankareh Shale	Permian	Carboniferous
Calcareous with sandstones and shales. "Mid-red" shale separates more calcareous upper from more arenaceous lower portion. Carries large fauna, with many new fossil species, chiefly pelecypods including *Pentacrinus* sp., *Myalina permiana*, *M. aviculoides*, *Aviculipecten curticardinalis*, *A. Weberensis*, *A. parvulus*, *A. occidaneus*, Lingulas, Spirifers, Dentalia. Forms country rock for replacement ore bodies and lodes.	1.190 feet	Thaynes Limestone	Permian	Carboniferous
Red shale—thinly bedded—fine grained. Bears ripple marks, mud cracks, raindrop imprints. No direct economic importance.	1,180 feet	Woodside Shale	Permian	Carboniferous
Calcareous with interbedded quartzite, sandstones and some shale. Carries Lingulidiscina sp., Productus cora, Productus sp., Plagioglypta canua. Euphemus subpapillosus, Bellerophon, sp. Forms country rock, for principal bonanza replacement ore bodies.	590 feet	Park City Limestone	Pennsylvanian	Carboniferous
Gray quartzite, massively bedded, homogeneous, dense. Carries, in Weber Canyon, *Lingula* sp., *Productus subhorridus*, *Schizodus* sp., *Plagioglypta canua*, *Euphemus subpapillosus*. Forms wall or walls of lead-silver lodes.	1.350+ feet	Weber Quartzite	Pennsylvanian	Carboniferous

Columnar section of portion of Carboniferous, Big Cottonwood Canyon, Wasatch Range, Utah

Character.—That part of this formation which outcrops in this region is made up of gray quartzite, with comparatively insignificant exceptions of cherty patches and intercalated limestone. This, the upper portion, is characterized by its general massiveness, both in bedding, which is rarely less than 4 and frequently 8 to 15 feet in thickness, and in absence of parting planes. On fresh fracture it is light brownish-gray in color, and it weathers to a glistening polished surface of a lighter whitish shade. The normal quartzite is fine, even-grained, and dense. The exceedingly brittle nature of the rock causes it to chip into sharply angular irregular fragments, or, when ground up in a fracture zone, to appear as a glistening white, sugary portion, inclosing less finely comminuted quartzite. The cleanness of the rock has been demonstrated by repeated chemical analyses, which show a very high percentage of silica. Thus analysis of a specimen of this quartzite from Big Cottonwood Canyon shows 95.80 per cent. of silica.

These lithologic characteristics are maintained with remarkable uniformity throughout the formation. Exceptions noted within this district are so rare as to be insignificant.

Topographically this quartzite stands up as knobs or ledgy massive blocks and as prominent broad spurs falling off by precipitous slopes.

That part of this great formation which is not present in this area, embracing the middle and basal portions, outcrops in prominent cliffs just south of this district. Excepting a few thin limestone beds near its top, the middle portion is massive quartzite, and in the lower part the intercalated limestone members increase in number and thickness. In Big Cottonwood Canyon the massive, dense character of the quartzite is preserved, and a few limestones are intercalated. A thin, crinoidal sandstone occurs about 130 feet from the top; a thin, pitted, cavernous, grayish-white quartzite, 460 feet below that; and a thinly banded, calcareous quartzite, 430 feet farther down. In Weber Canyon this great formation is most characteristically exposed as a massive, dense, homogeneous quartzite. The insignificant exceptions are a curiously pitted and marked horizon of quartzite just below the top and a few thin limestones in the basal portion.

Distribution and thickness.—The main area of this formation

exposed in this district is an oblong tract which extends south from Park City about 3 miles, with an average width of a mile. From Bald Mountain an irregular, much broken arm extends eastward between two great faulted zones, and to the south and southwest about the eastern end of Bonanza Flat are isolated horses in intrusives. This quartzite forms the outcrops on the slopes which inclose Park City on all sides. It is particularly well exposed on the salient bluffs west of the city, and is deeply incised by each of the canyons which lead south up to the mines. Characteristic outcrops have been revealed in Woodside Gulch by cutting the King Road between the Alice and Woodside properties; in Empire Canyon in the vicinity of the adits to the Daly Judge and to the Alliance tunnels, and in upper Ontario Canyon.

The thickness of the portion of this formation which appears in this district cannot be determined precisely, because nowhere within the area was a continuous exposure observed. The Ontario No. 3 shaft and workings cut "Ontario" quartzite, dipping about 20 degrees, to a depth of 1,620 feet, or a thickness of approximately 1,500 feet. The collar of the shaft lies on the side of a canyon which has been cut deep into the formation below its upper contact. This contact is exposed elsewhere to the north and northwest, but the thickness of quartzite which has been removed by denudation down to the stratigraphic horizon in which the collar of the shaft is located is uncertain, except that it is several hundred feet. The thickness of Weber quartzite exposed within the district may thus be regarded as approximately 2,000 feet. The minimum thickness of the underlying portion would be 1,500 feet. The accurate determination must await the working-out of structure and measurement of any possible great faults. Pending that, it may be tentatively considered as 3,500 feet. The thickness of the part exposed on the north side of Big Cottonwood Canyon was 1,340 feet. King and the geologists of the Fortieth Parallel estimated the thickness exposed in Weber Canyon to be 6,000 feet.

Age and stratigraphic relations.—The geologic age of the Weber quartzite was regarded by the early geological workers in this region as "Upper Carboniferous." They did not find fossils in the quartzite itself, but based this conclusion on the stratigraphic relation of this formation to fossiliferous limestones above and below.

During the present investigation paleontologic evidence was obtained from the quartzite itself, from limestone intercalated in its lower portion, and from overlying limestone formations, which definitely proves the age of the Weber quartzite to be "upper Carboniferous". During the season of 1903 Dr. T. W. Stanton discovered fossils in the quartzite in Weber Canyon. They occurred about 2 miles west of Croydon Station, and at 1,800 to 2,000 feet below the top of the Weber quartzite formation.

These fossils prove this quartzite to be of Pennsylvanian (upper Carboniferous) age. No fossils have been found, in the quartzite within or adjacent to the Park City district. Definite faunas were obtained, however, from limestones intercalated in the quartzite on the north side of Snake Creek which underlies the part which outcrops in the Park City area. These collections (101–7), like those from the formation in Weber Canyon, show faunas of Pennsylvanian (upper Carboniferous) age. Further, faunas from overlying limestone formations in both the Park City and Weber Canyon areas are Pennsylvanian. Accordingly the occurrence of Pennsylvanian faunas in the base of this formation and overlying limestone demonstrates that the age of the Weber quartzite is Pennsylvanian. The transition in Weber Canyon from the underlying great Wasatch limestone formation to the Weber quartzite is by gradually increasing siliceous contents through varicolored sandstones, which give way to alternating limestones and quartzites, and finally to quartzite with intercalated limestone. In Snake Creek the passage upward and northward into the Weber quartzite is by a corresponding succession of limestones intercalated in quartzite.

The passage from this great quartzite into the overlying formation had been subjected to considerable study without definite results. Accordingly in the present investigation special attention was given to this question. It had been reported by one geologist that a marked unconformity existed between this quartzite and the overlying limestone. During the present survey no unconformity was found. On the contrary, excellent exposures showed on careful inspection apparently complete conformity. The lithologic character of the sediments also indicated that a full record is here shown of a gradual normal transition. Exposures in Woodside Canyon show a succes-

sion of calcareous sandstones, normal sandstones, and arenaceous quartzites immediately above characteristic massive Ontario quartzite —apparently a normal transition. In Big Cottonwood Canyon, a few miles to the west of this area, the quartzite gives way upward to a sequence of sandy beds. In Weber Canyon the precise contact was not sufficiently exposed to demonstrate conformability, but the limit and extent observed gave no evidence of unconformity. Immediately overlying normal Weber quartzite is a coffee-colored and white sandstone, variably coarse and fine, about 150 feet thick, succeeded by the regular calcareous succession.

These accordant features, lack of reliable evidence of unconformity, and a lithologic succession tending to show conformity between these formations, are further supported by paleontologic evidence. In the Park City District the base of the overlying limestone formation carries a distinctive fauna. Members of this same fauna, as indentified by Dr. Girty, occur in Weber Canyon in the equivalent limestone at a corresponding distance above the quartzite (about 250 to 300 feet), and also about 1,800 to 2,000 feet below in Weber quartzite. This fact in itself seems to show conclusively that no break in the paleontologic succession took place, and thus that there was no break in the sedimentation, or, in other words, that the Weber quartzite and the overlying limestone formation are conformable.

PARK CITY FORMATION

Name.—The Park City formation is named after the district, in recognition of the fact that it is the formation which has yielded the bonanzas that during the last decade have made the district famous.

Character.—This formation is made up in large part of calcareous members, but it also embraces several sandstones and quartzites. In general, it comprises a thick limestone in its lower part, several minor limestones in its upper part, and a number of thin calcareous beds toward the base, with intercalated quartzites and sandstones. Along the King road the lower portion of the formation is seen to be made up of normal gray limestones, cherty limestones, brown calcareous and shaly sandstone, red, brown, and olive shales. The lower half of the formation is there seen to include two important limestone members and three minor quartzites. Overlying these,

and forming the top of Treasure Hill, are various types of siliceous beds, sandstones, quartzites, etc.

The exposure in the type section a few miles to the west in Big Cottonwood Canyon presents the best section observed.

TYPE SECTION, BIG COTTONWOOD CANYON

Thickness in Feet	*Description*
19	Grayish-white limestone, with fine gray and white cherts increasing toward bottom.
19	Shale and fine buff sandstone.
7	Dark-gray limestone, thin chert, red shale, and porous loose member at base.
11	Sandy shale.
21	Yellowish-gray quartzitic sandstone, changing into cherty white limestone below.
52	Gray and white banded chert, with few white sandstone intercalations.
8	Fine calcareous sandstone, with lentils of chert and brecciated fragments of sandstone.
104	Float of buff sandstone and shale, becoming more shaly and calcareous at base.
18	Siliceous arkose, comprising mainly rounded quartz grains and feldspars cemented with ferruginous material.
20	Compact grayish quartzite.
8	White, compact, sugary sandstone, fossiliferous at base.
30	Fine gray and pink, massive quartzite, with brown sandstone and gray-white chert bands near base.
27	Light-gray limestone, weathering whitish gray with an imbricated pattern; fine gray limestone near base; carries good faunas at two horizons in particular, 20 and 55 feet above the base respectively.
24	Gray calcareous sandstone.
9	Fine gray limestone.
36	Float showing bits of grayish and brown calcareous sandstone.
22	Sandy limestone, more calcareous at base, with cavernous weathered surface.
31	Float, upper sandy beds at top of Weber quartzite.

Distribution.—The Park City formation extends around the center of the district in the general form of a U (with base pointing north). Its irregular and interrupted outcrop stretches from Bonanza Flat northward across the prominent eastern spur, passing the Daly West, Daly, and Silver King mines, thence northerly to a point opposite

Park City, where it swings northeast and eastward around to the north of the city, whence, continuing the curve, it reappears with a southerly strike near the base of the eastern slopes of the range. The continuity of this general course has been much interrupted by intrusives, extrusives, and faulting. The most characteristic, and also the most extensive, exposures are those lying west and east of Park City, forming respectively Treasure Hill and Twin Knobs.

This formation characteristically forms domar knobs and spurs of moderately steep slope intermediate in degree between the resistant quartzite below and the non-resistant shale above. No good natural exposures of the entire formation are known in this area. The absence of cliff-making members, the presence of weaker members, and the thick growth of aspen and brush which characterize this formation, all contribute to cover its surface, to render it inaccessible, and to prevent careful examination and measurement of its members.

Thickness.—The exposures in this area do not afford a basis for a close estimate of the thickness of the Park City formation. Crosscuts in the Silver King and Daly West mines should, under normal conditions, yield the desired data, but strike-faulting in both properties has so complexly duplicated the succession as to render measurement of its thickness little more than approximation. The total thickness indicated by the Treasure Hill body is approximately 700 feet. The best and the only reliable section observed is the type section in Big Cottonwood Canyon, described above. The thickness of this formation at that locality measured 590 feet.

Age and stratigraphic relations.—The age of the Park City formation is proved, by several faunas collected from calcareous members in the district in Big Cottonwood Canyon and in Weber Canyon, to be Pennsylvanian (upper Carboniferous). Two of the type fossils are particularly indicative: the Bellerophon, as seen in the lower portion of the formation along the King road, in Woodside Gulch, and the Orbiculoidea, of common occurrence in the gray shaly limestones, the lower part of the formation throughout the district. The identification of these faunas in the Cottonwood and Weber Canyon regions makes possible the correlation of this formation with its equivalents to the west and north. The association of *Bellerophon* sp., *Productus cora*, and *Orbiculoidea* sp., and the stratigraphic position of these faunas

leads Dr. Girty to suggest the correlation of this formation with the Bellerophon limestone in the Uintas. With regard to the position of the ore-bearing limestones of this formation in comparison with that of others in the Utah mining camps, they appear to be somewhat higher than the Highland Boy, Commercial, and Jordan limestones at Bingham (upper portion of the Weber quartzite); higher than the Great Blue limestone at Mercur (the Wasatch, Mississippian, or lower Carboniferous); higher than the Eureka and Godiva limestones at Tintic (Mississippian); and higher than the great limestone of Emma Hill at Alta in middle Cottonwood Canyon (Mississippian or lower Carboniferous). Thus the Park City formation is much younger than any of the limestones in Utah which have been found to bear ore bodies, except those at Bingham, and it is believed to be next younger than the Bingham formation.

No unconformity was observed with either the underlying Ontario quartzite or the overlying shale, or between members within the formation. Accordingly it would seem that sedimentation proceeded unbroken from Mississippian time on through that period of the Pennsylvanian represented by the Park City formation.

WOODSIDE SHALE

Name.—The Woodside shale is named after Woodside Gulch, as the best exposed section of these sediments in the district is at the head of this gulch, on the slope which overlooks the Silver King plant from the west.

Character.—This great formation is a lithologic unit, being composed from bottom to top, without significant exception, of fine-grained, dark-red shale. A shaly parting sometimes gives way to very thin laminations, but the general homogeneous lithologic character is maintained with wonderful uniformity. In rare exceptions a slight increase in coarseness of texture produces a fine grained sandstone, or variations in color result in buff, brown, and greenish-gray shales; but such variations are extremely limited in number and extent.

The characteristic topography which has developed on such a lithologically homogeneous formation is a full, even, uninterrupted slope. This is commonly densely overgrown with rank grasses, shrubs and aspen.

The formation has no direct economic importance, as it affords neither ore bodies nor building stone, nor other economic products. Indirectly, however, its tendency to take off surface drainage and its enormous capacity for water render it an important factor in mining, especially in sinking deep shafts or in running long tunnels.

Distribution and thickness.—The Woodside shale appears in this district in three principal areas. In a highly metamorphosed condition as spotted dark-red and green argillite it occurs on the north face of Jupiter Peak and northward along the east side of Pioneer Ridge, and also as an argillite in the gap next west of Lucky Bill gap and on the north side of the Quincy spur. In its normal development it appears northwest of the Daly West shaft from the Morgan shaft to the Diamond-Nimrod shaft and along the west side of Empire Canyon, and especially characteristic in the slope above and to the west of the Silver King mine. To the east of Park City it reappears striking southerly on the eastern slope of the range.

The thickness of this shale varies considerably. In the type section of Big Cottonwood, which was studied and measured with unusual care, this formation was found to be 1,180 feet thick. In the Park City district the best opportunity for its determination was afforded by the sinking of the deep shaft by the Silver King Consolidated Company, although even this is not entirely free from possibly inaccurate estimate owing to faulting. This shaft is located on the northeast side of Crescent Ridge just over the divide northwestward from the Silver King property. It passed through this red-shale formation for a distance of 800 feet, which, reckoning the average dip as 30°, affords a thickness of 700 feet.

Age and stratigraphic relations.—No fossils were observed in this shale, neither was any stratigraphic evidence found which would directly connect this formation in age with either of the inclosing fossiliferous formations. Lithologically, however, this shale finds its equivalent in one important member and several thin ones in the next overlying formation and in the great thickness of red shale of the Ankareh formation. These lithologic resemblances show that the conditions under which this formation was deposited were those which prevailed during the deposition of the succeeding rather than that of the preceding formation. Accordingly the Woodside shale

will be grouped with the overlying fossiliferous limestone as of Permian age.

THAYNES FORMATION

Name.—This formation is named Thaynes after a canyon whose deep and extended incision affords the best exposures of this formation within the district.

Character.—This is essentially a calcareous formation. It comprises two parts separated by a red-shale member, each made up of limestone, calcareous sandstone, normal sandstone, and shale. Most of the true limestones are in the upper part, and the sandstones predominate in the lower part, though each type is found throughout. A very characteristic lithologic type occurring at many horizons in the formation is a dense, homogeneous, blue-gray, calcareous sandstone, which appears superficially to be a limestone, but on exposure to the weather loses its low calcareous content and becomes a medium fine-grained, brown sandstone. These are among the richest fossiliferous members of the formations, as is shown below. These members, the abundant and characteristic faunas, and the red-shale member—the "mid-red" shale—serve to mark this formation and to enable one readily to distinguished it from the Park City formation. Topographically, the outcrop forms abrupt cliffs, and the dip slopes and basset edges, broad flat slopes. Its surface is brushy and ledgy. A number of partial sections were measured and studied with great care for purposes of correlation, identification, and structural proofs. No complete sections or exposures which were not complexly faulted, intruded, or metamorphosed, which would serve for a standard section, were found within the district. The nearest point where suitable exposures could be found was about 3 miles west, in the north side of Big Cottonwood Canyon, where in several parallel spurs this formation occurs in excellent unbroken exposures. The composition of the formation in that section, including lithology, thickness, and fossil characteristics, is briefly stated below:

SECTION OF THAYNES FORMATION (PERMIAN) IN BIG COTTONWOOD CANYON

Thickness in Feet	*Lithology*
1	Sandstone, massive, even, fine-grained, basal member, Argenta formation.
1	Limestone, blue, locally sandy, fossiliferous.

Thickness in feet	
12	Shale, fine, gray-green.
½	Limestone, blue-gray, cavernous, fossiliferous.
2½	Limestone transition from shale through sandstone, fossiliferous.
14	Sandstone, gray-brown, with calcareous shale intercalations, fossiliferous.
5	Shale, maroon, fine-banded.
½	Limestone, gray, impure, semicrystalline, fossiliferous.
24	Limestone, light gray-blue, massive, sandy, fossiliferous.
16	Shale, gray-brown.
5	Limestone, impure, gray, massive, fossiliferous.
4	Shale, gray to buff.
14	Sandstone, massive, gray-brown, vertical sheeting, fossiliferous.
42	Shale and sandstone, green to brown, calcareous intercalations.
4	Sandstone, gray, finely laminated, chert lenses.
8	Shales.
20	Limestone, fine, blue, with intercalated ripple-marked sandstones, lenticular gray cherts, and biotitic bed, bearing fossils.
15	Shale, olive.
4	Sandstone, olive-gray, massive, weathers rusty, trails, fucoids, and imprints.
5	Limestone, bluish, matrix inclosing "tangle" stringers of ferruginous sandstone.
4	Limestone, impure, blue, very fossiliferous.
19	Shale, olive, fine-grained.
7	Limestone, sandy and shaly.
8	Limestone, blue to gray, spheroidal weathering, fossiliferous.
14	Débris, lime with intercalated shale.
14	Limestone, dark blue, locally shaly, weathers rough, several highly fossiliferous horizons.
10	Shale, brown, inclosing sandy bed.
5¾	Limestone, gray-blue, gray chert lenses, fossiliferous.
4	Shale, brown with green tinge.
6	Limestone, coarse shells, gray chert band.
14	Limestone, dark blue, sandy, massive.
35	Limestone, deep blue, weathers rusty, fossiliferous.
11	Sandstone, calcareous, rusty, breaks in slabs.
10	Limestone.
66	Sandstone, gray-black, shaly, bands black slaty shale, fossiliferous.
168	Sandstone, calcareous, finely laminated, highly fossiliferous.
20	Shale, maroon.
30	Float, varicolored shale.
64	Shale, green, buff, olive, maroon, yellow.
34	Sandstone, gray, calcareous, intercalated shales.
5	Limestone, gray, intercalated, calcareous, gray sandstone.
14	Sandstone, greenish-brown, intercalated shales.

Thickness in feet	
4	Limestone, gray-blue, fossiliferous.
17	Shale, olive, with three fossiliferous argillaceous limestones.
5	Limestone.
370	Limestone, blue; shale, olive-brown; sandstone, calcareous; alternating series, varying much in color and texture, fossiliferous.

Talus, containing shale regarded as top of Woodside formation.

Distribution and thickness.—The Thaynes formation is one of the two most extensively exposed formations in this district. On the western flank of the Park City anticline it forms both of the inclosing walls of Thaynes Canyon from head to mouth, all the middle and headward portions of White Pine Canyon, and thence strikes southwest into Big Cottonwood Canyon. It is again seen in the main fault zone of the district overlying the great mines. Thus it forms the prominent ledges west of the upper portion of Empire Canyon, just opposite the Daly Mine, the spur extending from the Daly West mine to Morgan Knob, and the cliffs which overlook the Daly Judge amphitheater. On the eastern flank of the anticline the cropping of this formation is exposed about the heads of Heber, McCune, and Pocatello gulches, and at the extreme southeast crops in a triangular area just north of Cottonwood Canyon.

The best measure of the thickness of this formation was obtained in Big Cottonwood Canyon, where, as shown above, the upper part amounts to 630 feet, the "mid-red" shale to 115 feet, and the lower part to 445 feet, the whole formation thus aggregating 1,190 feet. Within the Park City area proper no exposure was found suitable for measurement, so complex and universal was the deformation in this region. The difference in thickness of exposures of this formation on the eastern and western sides of the district may be apparent rather than actual, as on the Heber road near the top of the eastern exposure red-shale crops which is probably the "mid-red" shale, and the same is true in the Cottonwood exposure. It would thus appear that the eastern exposures embrace a portion of the formation only—that is, the part lying below the "mid-red" shale, the upper portion being either truncated by intrusives or buried by extrusives.

Age and stratigraphic relations.—Excellent fossil evidence indicates that the geologic age of the Thaynes formation is probably Permian.

Dr. Girty, who has examined the faunas collected from it and prepared the list of species given below, states that

"the fauna and horizon are those which in the Fortieth Parallel Survey Reports are called Permo-Carboniferous in the Wasatch and Uinta Mountains. The fauna consists almost exclusively of pelecypods, chiefly pectinoids, a few of which are described in the reports above referred to. With these exceptions the fauna was entirely new to me. . . . . It now seems probable that the fauna will be correlated with the Permian of the Grand Canyon section, and will prove to be in fact Paleozoic."[1]

The limestones and the peculiar calcareous sandstones are rich in organic remains. In their characteristic and distinctive fauna three forms are almost universally present, *Myalina*, *aviculipecten*, and *lingula*, while Spirifers and Dentalia are usually present in faunas from limestones. The first three forms are found throughout the Thaynes formation, including the highest and lowest members, and are indicative of this formation. *Pentacrinus*, which also serves as a valuable index, is limited to the part lying above the "mid-red" shale. The following species in the list submitted have been identified by Dr. Girty:

PARTIAL LIST OF PERMIAN FOSSILS IDENTIFIED IN PARK CITY DISTRICT

Pentacrinus sp.	*Aviculipecten curticardinalis*
Myalina permiana	*Aviculipecten Weberensis*
Myalina aviculoides	*Aviculipecten parvulus*
Aviculipecten occidaneus	

In addition to these recognized forms, Dr. Girty states that the collections from this formation in the Park City District include fully thirty new species, and that nearly as many more have been found outside the district.

In its stratigraphic relations this formation is intimately related to the two inclosing shale formations, in that during its deposition the same conditions frequently prevailed as during their deposition. No great unconformity either above or below was noted, though a slight unconformity by erosion was observed at one horizon within this formation, and others doubtless exist.

The persistence of certain members of the Thaynes formation is noteworthy. Thus the "mid-red" shale, with a thickness of only

[1] Extract from report on collections submitted by the writer for identification by Dr. Girty, Paleontologist, U. S. Geological Survey, dated August 11, 1903.

115 feet in the Park City area, is found 3 miles to the west in the Big Cottonwood region and 40 miles to the north in Weber Canyon. Still more noteworthy is the occurrence of thin limestones at equivalent stratigraphic positions in the formation and bearing identical faunas in this district, and again in the Big Cottonwood section 2 to 3 miles to the west. Not sufficient work in following special members was done to warrant the affirmation that this persistence or equivalency is actual stratigraphic continuity, though in the case of the thicker formations this is doubtless true, and it is probably true of some of the thinner limestones. This striking continuity probably indicates that the conditions under which these members were formed were brought about over extensive areas by wide-spread land movements of equal intensity throughout the region.

ANKAREH FORMATION

Name.—The name for this formation is taken from the ridge on which it attains its fullest and most characteristic development within the district. The ridge has been named by the writer for the purpose of rendering descriptions shorter and more definite. One of the most striking characteristics of this ridge is the red color imparted by the shales, and as *ankareh* is the word for "red" in the dialect of the Uinta Utes, the local Indian tribe, the adoption of the word *Ankareh* as the name of this ridge seems most fitting. The extension of the use of this term from the ridge to the formation is no less appropriate, as this formation constitutes the base of the main red shale and sandstone formation in the Wasatch, whose striking red color is most characteristically displayed on prominent spurs immediately west of Park City.

Character.—As a whole, this formation is composed of siliceous detrital deposits. They are chiefly red shales, which frequently become sandy through considerable thicknesses. It also includes a number of well-marked beds of rather coarse, whitish-gray sandstone, which range from 20 to 55 feet in thickness. A few fossiliferous, grayish-blue limestones are also intercalated, but these are exceptional and only a few feet thick. The division between this and the underlying formation is made on lithologic grounds, calcareous members characterizing the Thaynes formation and siliceous the Ankareh

formation. For the basal member the coarse, massive sandstone is taken which lies at the base of the red shale as a whole, and immediately overlies a thin limestone. Only a portion of this formation occurs within this district, the highest part being marked by a prominent massive, white sandstone member.

The non-resistant character of the beds of this formation as a whole results in the topographic development along its outcrop of even full slopes, which are broken only by benches on the sandy members. These slopes are usually thickly covered with aspen, rank grasses and brush. They are dry, rarely forming water sources. No economic values, either in ore or in stone, have yet been found to occur in its members.

Distribution and thickness.—The formation outcrops in only two areas within the district. The principal one is an N-shaped zone in the extreme northwestern corner of the area; thence it strikes westerly, and is plainly visible in characteristic topographic and lithologic development on each of the succeeding ridges to the west of Park City which head at Big Cottonwood Canyon. The second area, which has never been recognized as such hitherto, is on Pioneer Ridge, between Crescent Ridge and Jupiter Hill, where red shale of this formation forms the spur between the Kearns-Keith or Sampson amphitheater and the Jupiter amphitheater immediately south.

The best exposure for the measurement of the thickness of that portion of the formation which crops in this district is at the west side of Thaynes, toward its mouth. This was carefully studied and measured, but, owing to frequent interruption by vegetation and débris, it is incomplete, and, owing to the probability of deformation by faulting, any estimate of the thickness would be of little value. In the Big Cottonwood standard section the thickness of the portion which crops in the Park City District was found to be 1,300 feet.

Age and stratigraphic relations.—The age of the Ankareh formation, so far as indicated by meagre paleontological evidence, is Permian. The fossil evidence on which this determination is based comprises three lots from the standard Big Cottonwood Section and scattering collections from within the Park City District. The lowest two lots, one from coarse sandstone, the other from a thin limestone, both within 200 feet of the Thaynes formation, belong with the fauna

of the underlying limestone, and like it are Permian. This definitely fixes the lower portion of the Ankareh formation as Permian, but the division between this known portion and the overlying shales and sandstones which have been considered Triassic, remains undetermined. In the standard section just below the main sandstone member, and in the Thaynes section in this sandstone succession, petrified wood and bark were found; but these hardly marked the age of the inclosing beds. For the purpose of this report the portion of this formation which lies within this district may be considered as Permian. The delimitation of the upper part may best be left to future workers in adjacent areas where the entire section is exposed.

Stratigraphically the lower part of this formation is shown by the character of the included faunas to belong with the Permian. Doubtless deposition took place without interruption between these formations. The transition upward into sandstones, which are well bedded and also coarsely crossbedded, points to probable depression from shore conditions to slightly deeper water and strong currents.

TRIASSIC

Within this district no sediments have been found which carry Triassic fossils. To the north and northwest, however, the Park City formations pass upward through several hundred feet of red shale into brown, red, pink, and white sandstones. These are frequently massive and heavily bedded, in striking occurrences are coarsely crossbedded, and toward the top are quartzitic. Disregarding possible faulting, they aggregate about 1,550 feet in thickness. The age of these sandstones has always been regarded as Triassic, as they overlie Permian and underlie Jurassic.

JURASSIC

Overlying these sandstones is a succession of fine-grained gray limestones several hundred feet in thickness, which yielded sufficient organic remains to prove them of Jurassic age. These roughly measured 400 feet in thickness, and were overlain by concealed, partly calcareous beds about 500 feet in thickness.

The following forms in these collections have been identified by Dr. T. W. Stanton:

Camptonectes pertenuistriatus Hall & Whitfield.
Cucullaea haguei Meek?
Astarte sp.
Pleuromya subcompressa Meek.
Cerithium? sp.
Nerinea sp.
Gryphaea calceola var. *nebrascensis* M. & H.
Pinna kingi Meek.
Cyprina? sp.
Pentacrinus sp
Ostrea sp.
Lima (*Plagiostoma*) *occidentalis* Hall & Whitfield.
Gervillia sp.

GENERAL STRUCTURE

In the course of mapping the above-described geologic formations in this district, and of reconnaissance work in adjoining areas, several structural features were discovered which bear significantly upon the location and deformation of the ore-bearing formations. Some time must necessarily elapse before the complete report giving these results can appear. Accordingly, in response to several urgent requests from operators for information, this opportunity is taken to present without further delay a general statement of some of the more important structural features.

The general anticlinal structure of the Paleozoic and Mesozoic beds which characterize the Wasatch as a whole is interrupted in this central portion by a transverse (east-west) anticline or dome. Sediments ranging from Cambrian to Tertiary here dip northerly and southerly quaquaversally from a series of laccolithic masses. These include, from west to east, the porphyritic granite of Lone Peak and Little Cottonwood Canyon, the granodiorite at the head of Little Cottonwood Canyon in the vicinity of Alta, the coarse and fine-grained dioritic masses at the heads of Big and Little Cottonwood Canyons, and the northeast extensions in the form of dikes. These several masses constitute a mammoth composite laccolith. It is noteworthy that these intrusions have taken place along a zone coinciding in location and course with the extension of the Uinta axis across the Wasatch. This fact, together with the influence of these masses in doming the structure athwart the general course of the Wasatch, naturally raises a query as to a similar influence in the formation of the Uintas. This transverse Wasatch dome and the Uinta dome are separated topographically, though not structurally, by a north-south

trough. Into this, and thus blanketing the surface connection of these structures, extensive and thick masses of andesite have flowed.

That portion of this region known as the Park City District is traversed diagonally by this axis. The sediments in this area have been cut, deformed, and altered by a series of intrusives, and andesite flows cover the sediments at the northeast. These sediments rim around the intrusives and dip off from their flanks. The area thus embraces the northeast end of the great composite laccolith of the middle Wasatch.

The broad structure of the formations within the Park City District proper is that of an anticline pitching northerly. The general strike follows the course of a U, the base of the letter being at the north. At the center, along the main axis which passes north-northeast just east of Park City, occurs an extensive area of Weber quartzite, from which the overlying younger formations dip—in general to the west side on the west and to the east on the east. Immediately north of Park City these strikes converge and unite to form the nose of the pitching fold.

This structure, however, is true only in a general sense, as it is greatly modified by minor folding and extensive faulting. Athwart this anticline, in a general east-west course, extends a series of intrusive masses. These include the diorite stock of Clayton Peak at the extreme southwest, east of this the stocks and dikes of andesite porphyry which extend eastward diagonally across this area and upward through all sedimentary formations from the Weber to the Thaynes, and next beyond to the east extensive thick flows of andesite. These are the highest members of the chain of intrusives which lie athwart the course of the range at this point. They occupy the normal position of sediments, and thus interrupt the general anticlinal structure above described to only a minor degree by local folding.

Three great systems of fracturing and faulting further break the broad structure, trending north-south, northeast-southwest, and northwest-southeast (east-west), respectively.

One of these fracture systems cuts across the nose of the anticline on its northeast side as a north-south line of dislocation, which is marked by the eastern inclosing wall of Deer Valley Meadow and Frog Valley. Along this fault the displacement has been such that

the eastern side lies farther south than the western. In the same deformational sense the western member, especially that area of Weber quartzite lying east of Park City and that forming Bald Eagle Mountain, has moved eastward up this same fault plane, overriding geologically higher formations. As a result of this extensive overthrust faulting, two formations, aggregating 2,000 feet in thickness, have been overridden until the Weber outcrops against the Thaynes formation. The economic importance of this discovery lies in the fact that the principal ore-bearing limestone of the district which had been believed hitherto to strike north from Park City and to disappear beneath the extrusives, in reality occurs immediately east of the settlement in an easily accessible locality.

The principal zone of fissuring in this region trends across the central portion of the district in a northeast-southwest direction and dips steeply toward the northwest. It embraces the lodes which have afforded the valuable output from the Ontario, Daly, Daly West, and Daly Judge properties. The faulting on the main fissure of the system in its eastern extent, the Ontario, as measured in the vicinity of Ontario shaft No. 3, was relatively a downward movement of the north or hanging wall side, aggregating 330 feet. Correspondingly great dislocation occurred on the most important member of this system in its western part, the Daly-Daly West fissure, also on other members; and in certain instances a relative downward movement of the *south* or hanging wall side of south-dipping fissures is clearly shown.

North of this zone members of the northwest-southeast system appear in a series known after its principal member, the Massachusetts fault. This may be best seen trending west-northwest and standing about vertical in the Daly Judge tunnel and at the Massachusetts shaft. Its structural importance lies in the fact that the north side has been moved along it relatively westward about 2,500 feet. Its economic importance arises from the fact that its recognition and solution answers the hitherto standing query as to the relation of the ore-bearing limestones of the Silver King and Daly West properties, respectively; namely, they are portions of the same formation—the Park City limestone.

A similar result of these east-west faults is shown on the west side

of Empire Canyon, opposite Daly shaft No. 2. The limestone cliffs forming that wall of the canyon terminate abruptly on the north, and the same beds (Thaynes limestone) reappear 5,000 feet to the west in Crescent Ridge, on the north side of a strongly defined east-west fault.

A significant fault structure has also been brought out in the course of this work to the east of the Ontario fracture zone, on the extreme eastern slope of the range. A block (or wedge) averaging 2 miles in width north and south, and made up of the regular sedimentary succession, including the Weber to Thaynes formations and intruded andesite porphyries, has moved bodily to the east at least 2 miles. Its northern limit is a strong east-west fault, followed by McHenry Canyon. Its southern wall is a companion fault which crosses Cottonwood Canyon near its mouth about a mile southeast of the Valeo Mine. The economic significance of this discovery is that the desirable ore-bearing limestones should not be sought in their normal strike and position, and that within the extent of this block they lie at least 2 miles beyond to the east at an unknown depth beneath thick andesite extrusives. The scientific bearing of this structure, however, is of deeper interest, in view of the present eager search for evidence on the manner of intrusion, especially as to the disposition of the rock which previous to intrusion occupied the space subsequently taken by the igneous mass. The general aspects of this occurrence are most suggestive.

From the foregoing statements regarding intrusives and structure, it is to be noted that a series of intrusives lie in a narrow east-west belt extending across the range; that these appear on other distinct evidence to have invaded this area from the west, breaking upward and eastward; that the intrusives in this area are thus the highest and easternmost members; that in the path and ahead of this chain of intruded igneous masses occurred the maximum deformation and dislocation; that slightly to one side on the north sediments were broken and driven eastward over geologically higher members; and that directly ahead of the invading wedge of intrusives the country gave way and moved eastward at least 2 miles.

RESTORATIONS OF CERTAIN DEVONIAN CEPHALOPODS WITH DESCRIPTIONS OF NEW SPECIES[1]

A cephalopod fauna remarkable for the form of some of its species as well as for the abundance of individuals occurs in the hydraulic limestone of Middle Devonian age near Milwaukee, Wis. The specimens are crushed to such an extent by pressure applied at various angles with reference to the vertical axis, that a hasty study would probably result in their separation into a large number of species and perhaps genera. In fact, early collectors were led to believe that at least twenty species were represented, whereas, all should probably be included in nine or ten species.

In order that these distorted forms might be clearly understood, and to reduce as much as possible the liability to error in their determination, restorations in clay and later in plaster were made from careful measurements of actual specimens. In these restorations it was found necessary to restore the apex without reference to the fossils, since in no specimen was that portion of the shell preserved in its entirety. For example, in *Gomphoceras calvini* the lower one and one-quarter inches of the restoration is hypothetical, although in *G. wisconsinense* practically the whole specimen is known. The transverse section was made circular in the restorations of all the species. In the case of *G. wisconsinense* this was doubtless the true shape, but it is possible that in two of the restorations (*G. whitfieldi* and *G. fusiforme*) the cross-section was elliptical.

The rim of the aperture of *G. wisconsinense*, *G. calvini*, and *G. fusiforme* is pretty well known, but in *G. whitfieldi* its exact contour is in doubt. It is difficult in all cases to determine the position, if any, of the hyponomic sinus.

It should be remembered that the restorations in this paper are in every case of the interior. If a restoration were made of the exterior, account must necessarily be taken of the thickening of that portion of the shell forming the chamber of habitation. In none of our

[1] Published by permission of the Director of the Wisconsin Natural History Survey. The writer is indebted to Dr. R. Ruedemann for suggestions and criticisms.

specimens is this thickening indicated, but it has been shown by Dr. R. Ruedemann[1] that in certain Ordovician cephalopods "the slight constriction of the living chamber [shown in the cast of the interior] is largely due to a thickening of the shell in apertural direction, evidently a gerontic feature." It is possible that the exteriors of the

FIG. 1.—Lateral view of an exceptionally well-preserved specimen of ***Gomphoceras wisconsinense*** N. S. The measurements from which the model (Fig. 2) was constructed were largely from this specimen. The original is from Milwaukee and is now in the Public Museum, Milwaukee.

upper portion of the shells of *G. wisconsinense* and *G. calvini* were much less concave than the interior, or were even convex.

A comparison of these restorations with the fossils shows that a number of the specimens which appeared at first to be distinct species

[1] *Cephalopods of the Champlain Basin* (1906), p. 503, Fig. 57.

are only peculiarly distorted individuals of well-marked species. The species most distorted is *G. wisconsinense*, a unique and beautiful fossil. In this species it appears that the shell was comparatively thin. The peculiar shape of the shell probably caused a whirling motion as the dead animal sank through the waters to the soft bottom of calcareous mud, where it rested in the position it had in the water immediately before striking the bottom. As a result of this whirling motion, it was seldom that two individuals struck the bottom at precisely the same angle. The effect, whether due to impact or to the weight of the superimposed sediments, was a distortion in different planes resulting in a great variety of fossil forms. In the case of the other species discussed in this paper it appears either that the shells were stronger, or that they reached the bottom with their vertical axis in approximately a horizontal position. Because of one or both of these conditions, the outlines, except in the transverse section, is little changed.

FIG. 2.—A restoration in plaster of *Gomphoceras wisconsinense* N. S. The shape of the apex is somewhat in doubt.

The outline of the shells, as has been said, is quite well known, but the internal structure is poorly preserved. The air-chambers are usually preserved, but the position of the siphuncle is, in some species, in doubt, and in only one species is the relation between the siphuncle and hyponomic sinus shown.

The impossibility of determining the position of the siphuncle compels the use of the broader classification used in the older literature.

Gomphoceras wisconsinense n. sp.

(Figs. 1, 2, 3)

Description.—Shell very large, straight, extremely gibbous. Longitudinal section like a pointed amphora. Between the last septum and the apex the

shell rapidly enlarges, becoming ventricose, and then more gradually narrows to near the aperture, where it flanges out.

Chamber of habitation large, about one-third the total length of the shell, gradually enlarging to the last septum. In all specimens the chamber is concave near the aperture, but not in the same degree. No other specimen shows this

FIG. 3.—Exterior view of a crushed specimen of *Gomphoceras wisconsinense* N. S.; with a parasitic growth of coral. The dark band near the top of the specimen is a band of pyrite or marcasite which is present on practically all of the specimens a short distance above the last septum, the significance of which is not understood. The original is from Milwaukee and is now in the Public Museum, Milwaukee.

character as strongly developed as the one figured (Fig. 1). Diameter of an uncrushed specimen about 10.5^{cm}. Apertural margin straight.

Air-chambers more than 20, increasing in frequency toward the apex and

varying in width from 16^{mm} near the chamber of habitation to less than 5^{mm} near he apex.

Surface and siphuncle unknown.

One individual of medium size which is crushed laterally measures about 22^{cm} in length and 15^{cm} in its greatest diameter, the actual diameter of the circle being about 10.5^{cm}.

This species most resembles *Gomphoceras mitra* Hall from the Upper Helderberg Limestone of Lexington, Ind.,[1] but differs from it in essen-

FIG. 4.—Exterior view of the concave portion of a well-preserved specimen of *Gomphoceras calvini.*

FIG. 5.—View of *Gomphoceras calvini* N. S., showing the unsymmetrical shape of the upper portion due to the leaning to one side of the chamber of habitation.

tial points. A more careful study of certain species of Gomphocerases from New York, Indiana, and Ohio will show a close relation to *G. wisconsinense.*

Specimens of this cephalopod occur rarely in the Milwaukee Cement Quarry. They are called "horses' hoofs" by the quarrymen because of a fancied resemblance to a hoof. The many shapes

[1] *Paleontology of New York*, Vol. V, Part 2, p. 330, and Plate 119, Supplement Vol. V, Part 2.

in which they occur—due to crushing—have given rise to the belief that a number of species are represented. This, however, does not seem to be the case, as a comparison with the restoration will show (Fig. 3). The shell appears to have been quite thin and easily distorted, in some cases one side being apparently pushed in until it became concave and in contact with the opposite side.

FIG. 6.—Transverse section showing the marginal position of the siphuncle in a crushed specimen of *Gomphoceras calvini* N. S.

Named for the state of Wisconsin.

Locality.—Milwaukee Cement Quarry, Berthelet, Wis.

Gomphoceras whitfieldi, n. sp.

(Figs. 9, 10)

Description.—Shell medium, sub-triangular in a longitudinal section. Transverse section oval or circular. Conch rapidly and regularly enlarging to the point of greatest transverse section, which is about midway between the last septum and the aperture of the chamber of habitation, thence contracting more gradually to the aperture. Apical angle about 45°.

Chamber of habitation wide, but very short; length in one specimen about 3.5^{cm} and greatest diameter about 6.25^{cm}. Aperture large, oval or circular in the border of which there appears to be a sinus.

Air-chambers regular, varying little in depth from the chamber of habitation to near the apex.

Surface and siphuncle unknown.

Length of two individuals about 13^{cm}; greatest diameter of a crushed specimen about 9^{cm}.

This species differs from *G. calvini* in its more acute apical angle, its symmetrical form, and its shorter chamber of habitation; from *G. breviposticum* and *G. fusiforme* in its greater size, relatively shorter chamber of habitation, and more obtuse apical angle.

FIG. 7.—Restoration in plaster of *Gomphoceras calvini* N. S. The shape of the apex and a portion of the apertural opening are somewhat in doubt.

In the restoration the only points in

doubt are the aperture and the transverse section, which may have been somewhat elliptical or subcircular.

Named in honor of Professor R. P. Whitfield, who, besides other well-known writings, has written several papers on the Wisconsin Devonian.

Locality.—Milwaukee Cement Quarry, Berthelet, Wis.

FIG. 8.—A specimen of a gomphoceras which appears to be a new species, but in which the characters are not sufficiently well preserved for specific identification.

FIG. 9.—Restoration of *Gomphoceras whitfieldi* N. S. In this restoration the cross-section is circular. It is, however, possible that the cross-section of the species was oval.

Gomphoceras calvini, n. sp.

(Figs. 4, 5, 6, 7)

Description.—**Shell large, fusiform. Transverse section oval or circular. Tube regularly enlarging from near the apex to the greatest transverse diameter which is posterior to the chamber of habitation, at the third or fourth septum; thence contracting to the aperture, but hanging to one side in old age.**

Chamber of habitation large. Air-chambers irregular, varying in depth within 9^{cm} of the chamber of habitation, from 5 to 10^{mm}. Hyponomic sinus shallow and apparently on the concave side.

Siphuncle in a crushed specimen 7^{mm} from the periphery on the concave side. Surface unknown. Internal mold frequently covered with parasitic bryozoa and worm (?) tracks.

In none of the specimens which are referred to this species is the apex retained. This species resembles *G. fischeri* of the New York Marcellus, but differs from it in the arrangement of septa. It also resembles *G. plena* Hall.[1]

The restoration of this species was difficult because of the poor

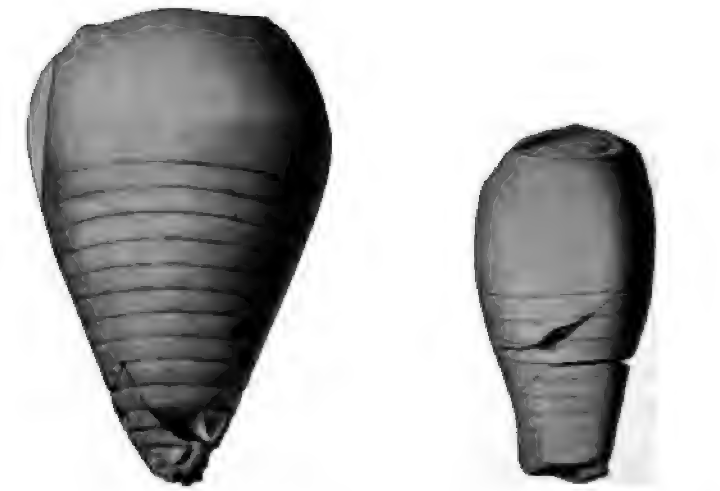


FIG. 10.—View of a crushed specimen of *Gomphoceras whitfieldi* N. S., in which the entire 'ength of the chamber of habitation is preserved.

FIG. 11.—A crushed specimen of *Gomphoceras fusiforme whitfieldi*, showing the position of the sutures and the length of the chamber of habitation.

preservation of the fossils. The apical angle and the rim of the aperture are somewhat in doubt, but are probably correctly shown. It is possible that the transverse section was broadly elliptical. Because of the unsymmetrical form the specimens are usually crushed in the same plane.

Named in honor of Professor Samuel Calvin, State Geologist of Iowa.

Locality.—Milwaukee Cement Quarry, Berthelet, Wis. They occur commonly in the "hard layer."

[1] *Paleontology of New York*, 1888. Supplement to Vol. V, Part 2, Plate 121 A.

Gomphoceras breviposticum Whitfield

(Fig. 13)

Gomphoceras breviposticum Whitfield: *Geology of Wisconsin*, Vol. IV (1873–79), p. 339, Plate XXVI, Fig. 15.

Description.—"Shell rather below medium size, very rapidly expanding from below upward, the rate of increase more rapid toward the base of the outer chamber than in the earliest stages of growth, and again decreasing in the same rate to near the middle of the chamber, and gently contracted above to the aperture. The rate of increase in the type specimen in a length of two inches below the point of greatest diameter, is from a little less than five-eighths of an inch to one inch and seven-eighths; septa moderate, those preserved being about one-eighth of an inch apart, siphuncle lateral in the specimen; aperture sharply sinuate on one side, at a distance of one-fourth of the circle from the position of the siphuncle. No evidence of the lobed contraction of the aperture, as in the Silurian examples of the genus, exists." The siphuncle is on the dorsal side.

FIG. 12.—Restoration in plaster of *Gomphoceras fusiforme whitfield.*

It is possible that *G. fusiforme* Whitfield and *G. breviposticum* Whitfield are of the same species. The differences in the chamber of habitation may be due to age. The shells are almost identical in size, in the depth of the air chambers, and the margin of the aperture.

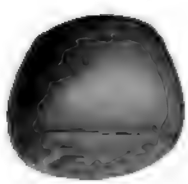


FIG. 13.—External view of the chamber of habitation and two air-chambers of *Gomphoceras breviposticum whitfield.* It is possible that this species is a young form of *G. fusiforme.*

Locality.—Milwaukee Cement Quarry, Berthelet, Wis.; "Whitefish Bay, near Milwaukee."

Gomphoceras fusiforme Whitfield

(Figs. 11, 12)

Gomphoceras (?) *fusiforme* Whitfield: *Geology of Wisconsin*, Vol. IV (1873–79), p. 338, Plate XXVI, Fig. 16.

Description.—"Shell rather below a medium size, very moderately expanding from below upward to near the middle of the outer chamber, as seen on the type specimen, about which it again decreases to the aperture somewhat more abruptly than below. Section circular, or very nearly so, the slight flattening of the specimen probably due to compression. Septa not distinctly defined in the specimen, but apparently about one-sixteenth to one-twelfth of an inch apart, and but

slightly concave." [Septa 5^{mm} apart at the chamber of habitation, and 3^{mm} apart 3^{cm} from the chamber. Siphuncle marginal.]

This species resembles *G. **tumidum*** Hall of the Chemung shales of New York.

It is possible that this is an old-age form of *G. **breviposticum***. For discussion on this point see description of that species.

Locality.—Milwaukee Cement Quarry, Berthelet, Wis., especially abundant in the "hard layer;" "Whitefish Bay, near Milwaukee."

FIG. 14.—Exterior view of a remarkably well-preserved specimen of *Gyroceras clarkei* N. S., in which what appear to be traces of both transverse and longitudinal color markings are retained. The original is from the Public Museum, Milwaukee.

Gomphoceras sp.

(Fig. 8)

Description.—An almost perfect specimen of a large Gomphoceras, differs from other Milwaukee cephalopods in that it is subfusiform and has a large chamber of habitation which contracts slightly toward the aperture. Septa 3 or 4^{mm} apart near the chamber of habitation, but 9 to 10^{mm} apart 6.5^{cm} from the chamber. Transverse section apparently elliptical. The greatest diameter appears to be at about the tenth septum.

Locality.—Milwaukee Cement Quarry, Berthelet, Wis.

Gyroceras eryx Hall, n. sp.

(Fig. 14)

Description.—Shell large, regularly coiled, forming a very open spiral, making about one and one-half volutions. Regularly enlarging from near the apex to the chamber of habitation. Oval or circular in transverse section. Apex unknown. Greatest diameter of the coil 17 ^{cm}.

Chamber of habitation comparatively short, and in one specimen appears to be contracted toward the aperture. Aperture not clearly shown, but apparently has a shallow hyponomic sinus on the convex side.

Septa numerous, regular, with straight transverse sutures which near the chamber of habitation are 9^{mm} apart on the convex side, and 5^{mm} apart on the inner side.

Siphuncle small, situated about one-third the diameter of the shell from the lower side.

What appear to be surface markings are preserved on the inner mold and show fine growth lines swinging backward and crossing the septa at an angle of about ten degrees. Fine irregular longitudinal lines which appear to be vestiges of color markings are also shown.

Locality.—Milwaukee Cement Quarry, Berthelet, Wis.

DISCOVERY OF CAMBRIAN ROCKS IN SOUTHEASTERN CALIFORNIA

N. H. DARTON[1]

During a recent trip in the desert region of southeastern California, I discovered an extensive series of fossiliferous Cambrian rocks in the vicinity of the Santa Fé Railroad. The locality is on the south end of a ridge known as Iron Mountain, 2 miles northwest of Siam Siding, in the eastern part of San Bernardino County. The rocks constitute the summit of the ridge and dip down its eastern slope. They lie on granite which rises several hundred feet up the western side. The adjoining country is a desert plain, but the ridge extends far to the northward. My opportunities for determining the structure and stratigraphy were limited, and only a partial section was measured. It comprises the following beds:

	Feet
Shales and sandstones	200+
Limestone	6
Gray shales	50
Limestone	8
Gray shales with few limestone and sandstone layers	250
Nodular limestone	25
Massive hard dark-blue limestone	50
Gray shales with calcareous sandstone layers	20
Gray sandstones and quartzites	500
Dark hard quartzites, conglomeratic at base	60
Granite	

Fossils were found in the limestone layers in the gray shales above the nodular limestone, and also in the gray shales below the 50-foot bed of dark-blue limestone. They consisted of fragments of trilobites and molluscs, which proved to be not specifically determinable, but Mr. C. D. Walcott believes them to be undoubtedly of Cambrian age, probably Middle Cambrian.

The contact with the granite is clearly exposed and was traced for about a mile. It is unquestionably a shore line and not a contact of

[1] Published by permission of the Director of the U. S. Geological Survey.

intrusion. Therefore the granites are of pre-Cambrian age. At one locality the granite is traversed by a dike of black basic rock on which the basal Cambrian conglomerates lie. As some of the granites of southern California are post-Paleozoic, it was of interest to find that the granite in Iron Mountain, at least, is of pre-Cambrian age.

In the vicinity of the gold mine, 2 miles southeast of Siam and almost in the line of strike of Iron Mountain, another high ridge consists of limestone and quartzite cut by a dark-colored, coarse-grained

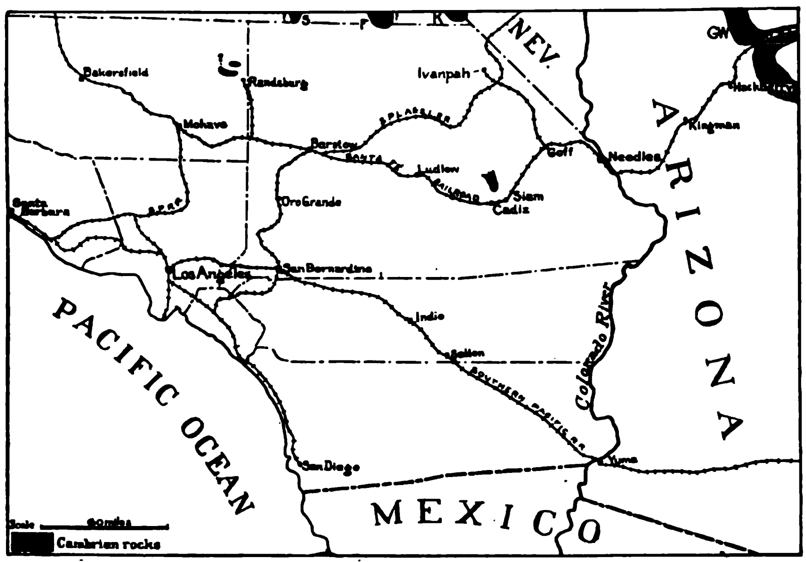


FIG. 1.—Sketch map of the southern California region showing occurrences of Cambrian rocks. GW, Grand Wash escarpment; K, Kingston Range; F, south end of Funeral Range; S, Slate Range.

granite. The exposure shows 200 feet or more of quartzite, overlain by greenish shale, capped by 800 feet of semi-crystalline limestone. No fossils were found, but some features of the limestone suggest that it may represent the Red Wall limestone of the Grand Canyon region 200 miles northeast. The quartzite lies on granite at this locality, but granite also cuts irregularly across the limestone, and apparently has caused its alteration.

The rocks above described are in the middle of a wide area of which the geology has never been studied. The location is shown in

Fig. 1, in which are also indicated the nearest occurrences of Cambrian rocks previously known. At GW is the Grand Wash escarpment on the western margin of the Arizona plateau traversed by the Grand Canyon of the Colorado. In this escarpment is the well-known succession of 1,000 feet or more of the Tonto (Middle Cambrian) sandstones and shales lying on pre-Cambrian granites and overlain by several thousand feet of Carboniferous limestones.

Cambrian rocks have been described by J. E. Spurr[1] on several ranges in the southern portion of Inyo County, extending to and slightly over the northern margin of San Bernardino County. These descriptions were based partly on his own observations and partly on notes of a trip made by Mr. R. B. Rowe. The most extensive areas which are in and near the Kingston Range (K, Fig. 1) were discovered by Mr. Rowe. The rocks here consist of over 1,500 feet of quartzites of various colors and limestone, sandstones, and shales. One mass of massive dark-blue limestone is mentioned. The rocks contain fossils at different horizons, some of which are stated to be lower Cambrian. They lie on gneisses and other crystalline rocks. In the southern end of the Funeral Range (F. in Fig. 1) there are about 2,000 feet of slates, limestones, conglomerates, and quartzites noted by Gilbert[2] and Campbell.[3] These observers found no fossils and Campbell suggests that the rocks may be of pre-Cambrian age. Mr. Spurr maps them as probable Cambrian. Some of the beds in Slate Range (see Fig. 1) and west of Randsburg are mapped as Cambrian by Spurr on the authority of H. N. Fairbanks,[4] who refers to them as "probably Paleozoic."

In the White Mountain Range, over 100 miles north, there are nearly 5,000 feet of sandstones, shales, quartzites, and limestones, in which Mr. Walcott[5] discovered an extensive series of Lower Cambrian fossils. In certain parts of the range the rocks are cut by great masses of intrusive granite.

In the Spring Mountain and Las Vegas regions, southern Nevada,

[1] U. S. Geological Survey, *Bulletin No. 208* (Washington, 1903).

[2] *U. S. Geographical Survey West of the 100th Meridian*, Vol. III, p. 170.

[3] U. S. Geological Survey, *Bulletin No. 200*, p. 14 (Washington, 1902).

[4] *American Geologist*, Vol. XVII, pp. 65, 149.

[5] *American Journal of Science, Third Series*, Vol. XLIX (1895), pp. 141–44.

Spurr[1] reports sandstones, limestones, and other rocks containing fossils probably of Middle Cambrian age.

Quartzites and crystalline limestones occurring just east of Oro Grande station believed to be Cambrian by Hershey[2] but no fossils were found in them.

[1] *Loc. cit.*, pp. 155, 165.

[2] *American Geologist*, Vol XXIX, p 288.

SOME NOTES ON SCHIST-CONGLOMERATE OCCURRING IN GEORGIA[1]

S. W. McCALLIE
Assistant State Geologist

The rather remarkable schist-conglomerate here described occurs in Lumpkin County, Georgia, about 2½ miles southeast of Dahlonega,

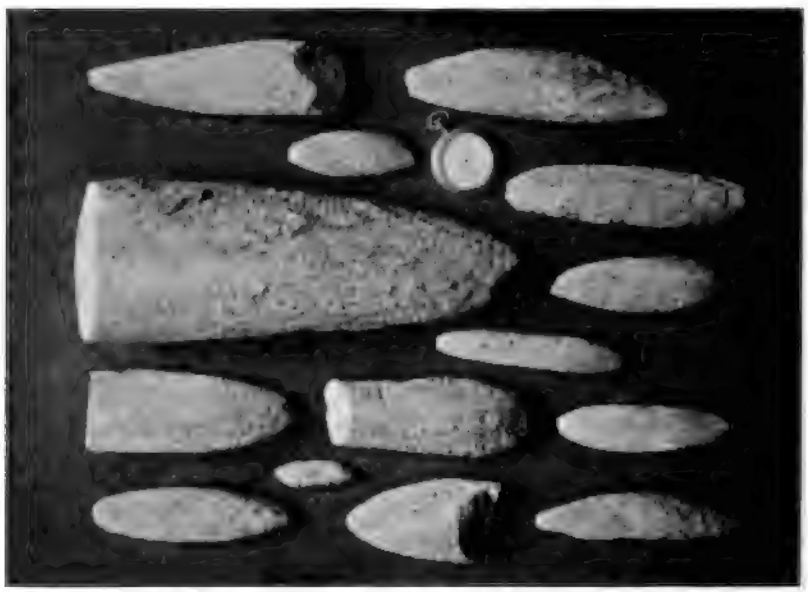


FIG. 1. — Stretched boulders weathered from schist-conglomerate, Lumpkin County, Georgia.

the county site. The best exposure is to be seen on the Dahlonega-Auraria public road at a point where the road traverses a narrow ravine along a small stream. The conglomerate here forms a number of low, disconnected bluffs on the south side of the road, and also occurs in the bed of the stream, where it forms a series of cascades. In passing the road, most persons would likely mistake the exposure for an outcropping of biotite-schist—a rock

[1] By permission of the State Geologist.

of frequent occurrence in the Dahlonega district. It is only by a close examination from different view-points that the true nature of the rock can be made out. Along a fresh cleavage plane the rock has every appearance of a biotite-schist with a comparatively small amount of quartz, while sections normal to the cleavage, or forming various angles therewith, reveal the presence of elongated bowlders and pebbles in greater or less abundance. The individual bowlders and pebbles are to be seen to the best advantage in the bed

FIG. 2.—Schist-conglomerate, showing stretched bowlders, Lumpkin County, Georgia.

of the stream, where the surface of the conglomerate has been polished by the action of the water. They are also to be seen in considerable numbers in the residual clays on the hill slope, where they have weathered from the outcroppings of the conglomerate at higher elevations.

The bowlders and the pebbles are both quite variable in size, but they are always greatly elongated in the direction of the schistosity.

Some of the larger bowlders attain a length of three feet. They are usually flat, spindle-shaped, with the greater diameter near the center. In cross-section they are ellipsoidal, the major axis being from two to three times as great as the minor axis, while the lengths of the bowlders themselves in many instances appear to be from five to

FIG. 3.—Schist-conglomerate, showing boulders and pebbles greatly elongated, Lumpkin County, Georgia.

fifteen times their original diameters. Owing, however, to a joint structure of the conglomerate, developed at nearly right angles to the schistosity, only the less elongated bowlders are to be found entire in the residual clays, the longer ones being usually divided by the

joints into two or more divisions. The surface of the bowlders is generally more or less roughened and occasionally pitted, as if having been attacked by some dissolvent agent. Striations, corresponding in direction to the long axis of the bowlders, are sometimes noticed, but such markings are not common.

A microscopical examination of thin sections shows that the bowlders and the pebbles consist almost entirely of interlocking grains of quartz, the chief accessory mineral being mica, which makes

FIG 4 — Schist-conglomerate, showing joint structure, Lumpkin County, Georgia

up, apparently, only a fractional part of 1 per cent. of the entire mass. The quartz grains in some cases are slightly elongated in the direction of the longer axis of the bowlders, but the extent of the deformation is by no means sufficient to account for the elongation of the bowlders themselves. The matrix, binding the bowlders and pebbles together, is made up chiefly of biotite and quartz, the former mineral being the more abundant. Magnetite also occurs in more or less abundance in the matrix in the form of crystals arranged along certain well-defined lines.

The rocks associated with the schist-conglomerate seem to be highly metamorphic clastics and intrusives, the former being represented by biotite-schist and the latter by diorite-schist. The age to which these altered clastics belong is not definitely known. They are probably early Cambrian or Algonkian, but they may possibly be even more recent.

ON AN OCCURRENCE OF CORUNDUM AND DUMORTIERITE IN PEGMATITE IN COLORADO

GEORGE I. FINLAY
Colorado Springs, Colo.

Introductory.—The purpose of the writer in the present paper is to record the occurrence of corundum in association with dumortierite and sillimanite in the rôle of igneous minerals in pegmatite, near Canyon City, Colo. The pegmatite dike in question is acid, its mineralogy is that of a granite, and it stands in epidote schist near masses of granite along Grape Creek. Corundum was first noted in the dike by Mr. Eugene Weston, of Canyon City. The occurrence is recorded by J. H. Pratt in the paper cited below.[1] The facts point to the igneous character of the pegmatite dike. It is therefore of interest to find corundum, dumortierite, and sillimanite in it as possible original constituents of such an acid rock. The dike does not show signs of metamorphism.

The complex of rocks appearing at the north end of the Wet Mountains in Colorado, on which the Ordovician and later Paleozoic series rests unconformably, consists largely of schist and gneiss, cut by veins of pegmatite and by diabase dikes. The wall rock in which the corundum-bearing pegmatite vein stands is dark, fine-grained schist. Under the microscope apple-green pleochroic hornblende appears as the most abundant constituent. Quartz is in small grains. The feldspar is deeply kaolinized, with muscovite as an alteration product. Epidote and magnetite are abundant. Apatite and hematite occur sparingly. Dark biotitic granite appears in extensive masses near the locality in question. Microcline, acid plagioclase, quartz, and biotite, with zircon, apatite, magnetite, and secondary hematite, are its constituent minerals.

Occurrence in the field.—The vein of pegmatite is seen on the ridge between the Rocky Mountain Boy and Joker claims on Grape

[1] J. H. Pratt, "Mineral Resources, Abrasives," *U. S. Geological Survey*, 1901, p. 45; see also *North Carolina Geological Survey*, Vol. I (1905), p. 238.

Creek, seven miles southwest of Canyon City, Colo. The abandoned tunnel of the Rocky Mountain Boy bears N14E from it. The distance from the mine tunnel is about 100 yards. The United States landmark No. 6236 has been cut on the vein at the summit of the ridge. The vein is from 40 to 80 feet wide. It stands vertically in the schist, appearing as a knob where it crosses the divide. It strikes N46E, running down the hillside for some distance on either hand until it is covered by the rock slide of the lower slopes. Two prospect holes have been made on it above the Rocky Mountain Boy. Along the south wall against the schist are stains of copper, malachite, and it is near this wall that the corundum occurs most abundantly.

Macroscopic description.—In hand specimens glassy quartz, in grains an eighth of an inch across, is the most abundant mineral in the pegmatite. The corundum appears to favor association with the quartz. White sugary plagioclase is present, with rarer crystals of pink microcline. Two kinds of mica are prominent, one white, the other black and much more abundant. The plates are at times half an inch across. Muscovite and biotite are indicated by the axial angles. Corundum appears as a local constituent of the vein in hexagonal crystals which are often half an inch in diameter. The mineral is glassy, and of a clear blue color, but not good enough to be of gem quality. The basal cleavage is prominent.

Microscopic description.—Under the microscope quartz, with the minute needles referred to rutile, is seen to be as abundant as are the feldspars taken together. Microcline, and acid plagioclase, probably albite, twinned on the albite law with occasional pericline lamellae, are observed. No carlsbad twins were noted. The highest symmetrical extinctions measured were 9°. Muscovite is unusually prominent. The corundum resembles glassy quartz. Rectangular cleavage cracks parallel to the base are, however, prominent. Negative crystals of hematite are often seen in it. Basal sections give a uniaxial cross without the rings which appear in the field of view when the figure of quartz is examined. Dumortierite occurs in very perfect pointed prisms 1^{mm} in length by 0.03^{mm} in breadth. They are faint blue. At times they make up bundles of radiating needles; occasionally they show a parting parallel to (001). Large, more massive columnar aggregates are very strongly pleochroic, from

faint blue to bright smalt-blue. Dumortierite could not be observed without the aid of the microscope. Bundles of radiating needles of sillimanite are occasionally met. Zircon occurs rarely. Secondary hematite is at times conspicuous.

Pyrogenic character of the corundum.—Corundum is described by W. G. Miller[1] in granitoid rocks over wide stretches in the province of Ontario, Canada. It is present in syenite, in nephelite syenite, and in anorthosite. Professor A. C. Lawson has given the name plumasite to a dike rock made up of oligoclase and corundum from Plumas County, California.[2] The granite of Nannie's Mountain, near Yorkville, S. C., carries corundum.[3] Morozewicz describes the occurrence of corundum in pegmatite in the Ural Mountains, intergrown with orthoclase,[4] and again as standing in the place of quartz in granite at Mikolskaja Ssopka, Ural Mountains, Siberia. He names this rock corundum syenite, and declares his belief that corundum occurs in these rocks as an original pyrogenic constituent.

The remarkable occurrences of large amounts of corundum in close association with peridotite in North Carolina have been described by Dr. J. H. Pratt and Professor J. V. Lewis.[5] The view is held by these writers that much of the corundum in this association is an original constituent of the rock. The distribution of the corundum with reference to the peridotite masses is (1) peripheral, along the contact between the peridotite and gneiss; (2) in the peridotite masses in banded veins containing, besides corundum, the minerals chlorite, clinochlore, spinel, and enstatite; and (3) corundum occurring alone, inclosed by peridotite (dunite) at the Hayes Mine, Yancey

[1] W. G. Miller, "Economic Geology of Eastern Ontario," *Seventh Report, Ontario Bureau of Mines*, 1897 (Toronto, 1898), p. 213. See also W. G. Miller, "The Corundum Bearing Rocks of Eastern Ontario, Canada," *American Geologist*, Vol. XXIV (1899), p. 276.

[2] A. C. Lawson, "Plumasite, an Oligoclase Corundum Rock near Spanish Peak, Cal.," *Bulletin, Department of Geology, University of California*, Vol. III (1903), pp. 219–29.

[3] J. H. Pratt and J. V. Lewis, *North Carolina Geological Survey*, Vol. I (1905), p. 222.

[4] J. Morozewicz, *T. M. P. M.* Vol. XVIII, p. 215, 1898.

[5] "Corundum and the Peridotites of Western North Carolina." *North Carolina Geological Survey*, Vol. I (1905).

County, N. C. Such an association as that last mentioned, (3), was observed in but one locality. Here it is quite possible, in the light of the experiments made by Morozewicz, that the corundum is an original pyrogenic constituent, as suggested by Dr. Pratt. The other occurrences, (1) and (2), can hardly be regarded as anything but secondary alteration products in veins. They show at times a remarkable banded structure, and they are made up largely of the minerals of alteration.

T. H. Holland[1] in the *Geology of India* records the occurrence of corundum in a variety of rocks. While he states that the occurrence of this mineral "as a constituent of normal lavas in the form of tabular crystals characteristic of those obtained artificially by Morozewicz during the devitrification of a slag leaves no doubt as to the possibility of its free crystallization from an igneous magma, as is admitted for other simpler though commoner oxides," he does not admit that the occurrences which have come under his observation are other than accidental, in the sense that the excess of Al_2O_3 was contributed from some extraneous source, or influenced by some rock other than the matrix of the corundum. Thus at Karutakalaiyam, in Madras, corundum occurs "in a coarse feldspar rock," but only near its contact with an eleolite-bearing rock rich in Al_2O_3. Corundum in India occurs in association with basic rocks, but near pegmatite dikes; and, according to Mr. Holland, influenced by such intrusions. The occurrence of corundum with sillimanite imbedded in orthoclase in an acid rock near Paparapatti, Madras, is referred to the contact effects of veins of pegmatite on pyroxene granulite.

The pegmatite dike near Canyon City, Colo., does not show any structures in the field pointing to its having been sensibly changed by metamorphic processes. The arrangement of the constituent minerals is not such as we look for in a metamorphic rock like gneiss. The development of the mica plates is not that which we should expect in a schistose rock. Garnet was not observed. The minerals in the pegmatite are essentially those in the granite which is near at hand. In the dike they are not arranged in lines parallel to the walls, as they have been observed to be in pegmatitic veins or dikes filled

[1] T. H. Holland, *Geology of India*, p. 10.

"by cementation."[1] Bearing in mind that "under proper conditions water and liquid rock are miscible in all proportions,"[2] the criteria for judging between pegmatite dikes which originate by igneous injection, and those in which heated waters play a larger rôle than molten rock, must be chiefly those of structure. The pegmatitic dike in question, by reason of its eugranitic structure in the field, appears to be among those which deal chiefly in molten rock, and are not greatly charged with heated waters. It lies very near the granite mass along Grape Creek. It tapers rapidly as it runs up the ridge. It has sent off occasional stringers into the schist six inches or more in width, sharply marked off, as are injections of igneous rock into fissures in the form of dikes. These observations support the view that the great dike in question is near the igneous end of the pegmatite series. It would appear that the acid magma was in places uncommonly rich in alumina, and that the excess of Al_2O_3 over that required to satisfy the alkalies and lime for the formation of feldspars crystallized as the oxide corundum. The mineral does not appear as a filling of cavities in the pegmatite. Under the microscope it bears the same indigenous aspect as do the other constituents of the rock. No evidence was obtained such as would point to a replacement of pre-existent minerals by the corundum. It is fresh and clear, and does not show itself as an alteration product of some other mineral. There is nothing to make it plain that the corundum has resulted from some other aluminous mineral by dehydration attendant on metamorphism. It is difficult to reconcile its distribution in the rock with the assumption that the Al_2O_3 needed for it was gained by the working-over in the magma of included portions of the wall rock.

Chemical characteristics of the pegmatite.—The calculation of the analyses of persalanes for their norms frequently presents an excess of Al_2O_3 to be referred to corundum. In the corundum-bearing subclasses of persalane are found quartz felsite, granite, quartz keratophyre, the Uralose rocks described by Morozewicz under the names corundum syenite and corundum pegmatite, and the two

[1] C. R. Van Hise, "Treatise on Metamorphism," *Monograph 47*, U. S. Geological Survey, p. 723.

[2] *Ibid.*

analyses of kyschtymite falling in the perfelic order Siberare described by the same author. The present occurrence of modal corundum is one in which the rock is much more siliceous than are the rocks above mentioned in the corundum-bearing subclasses of the persalanes. From a quantitative study of its mineralogy it is placed tentatively in the order Columbare of Class I. It is domalkalic. Dumortierite is a basic aluminic silicate, $Al_8Si_3O_{18}$, with a part of the aluminium replaced by boron. It might reasonably be expected, therefore in a siliceous rock rich in alumina, as is the pegmatite vein near Canyon City. Dumortierite has been reported from a pegmatite vein in schist at Harlem, N. Y.,[1] and from Clip, Yuma County, Ariz. It has been found in similar occurrences near Lyons, France, and near Schmiedeberg, Silesia, as well as in gneiss at Tvestrand, Norway. The present occurrence seems to justify the view that for it corundum and dumortierite are original pyrogenic accessory constituents, and that in other igneous rocks these minerals may occasionally play the same part.

[1] For a systematic account of the reported occurrences of dumortierite see W. T. Schaller, *Bulletin 262*, U. S. Geological Survey, p. 91.

GLACIAL ROCK SLIDING

F. O. JONES

A geological curiosity in the shape of a displaced mass of rock resulting from ice-pressure during the glacial invasion has been partially uncovered in the Voight quarry, three miles north of Elmira, N. Y., and one-half mile south of Latta Brook ravine. Reference may be had to the Elmira sheet of the United States Geological Survey, but the contour lines represent the topography only in a general way.

The quarry is located in the face of a ledge which extends out some 300 feet from the main hill. At its southern end the cutting is only 37 feet deep, but the linear extent is nearly 400 feet. The bottom is about 35 feet above the valley level, making the present approximate height of the point 70 feet.

Massive sandstones form the bottom of the quarry, but they rapidly thin out, and the upper third is very largely composed of shale. This formation has received the local name "High Point sandstones."[1] The strata have a northward dip of about 50 feet per mile, and their position indicates that the axial inclination of the Elmira anticline, to which they belong, is fully as great eastward. Their position was, therefore, an important factor in the amount of pressure required to move the load.

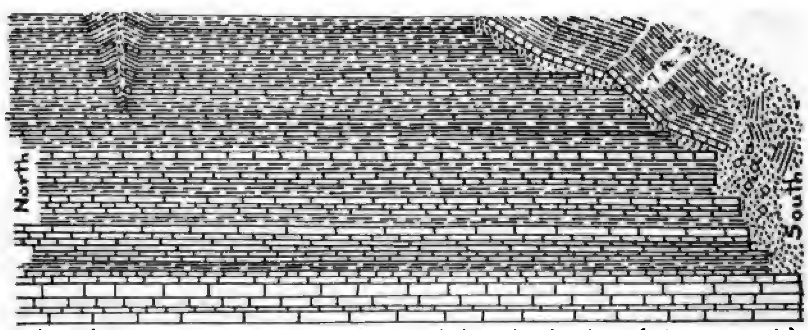
The south side of the ledge is in the form of steps or small terraces, which remain as they were in preglacial times, and it is down over this serrated slope that the rock mass was shoved. Its present form is indicated much more clearly by the accompanying sketch than it could be by a detailed description. The base or shoe on which the slide occurred is a hard, blocky sandstone 12 inches thick, and it is chiefly owing to this fact that its character can be recognized.

Any attempt to delimit the slide must be largely conjectural, owing to the till covering. There are 50 feet of the basal sandstone in sight, and at one point 7 feet of shale and thin sandstones remain

[1] Museum Bulletin No. 81, *Watkins and Elmira Quadrangles* (Albany, N. Y., 1905).

in place on it, which would make 8 feet the minimum thickness. The width and length could hardly have been less than 100 feet each, or a total of 80,000 cubic feet. It is probable, however, that the original dimensions considerably exceeded the figures given.

A further evidence of the pressure exerted by the ice is a V-shaped fault in the face of the quarry 90 feet north of the slide. The first noticeable disturbance of the strata is just above a 6-inch sandstone. From that point the width of the fault regularly increases until the top of the exposure is reached (11 feet), where the width is 7 feet and the vertical throw about 20 inches. The 6-inch sandstone can be traced northward from the fault for more than 200 feet, and the



Voight's quarry, Elmira, N.Y., showing rock displaced by glacial ice. (Not drawn to scale).

whole amount of rock moved may have approximated half a million cubic feet.

Although rare, Voight's quarry does not contain the only preserved example of glacial rock-sliding. Another instance occurs in an old quarry at Pine Valley, some six miles farther north and on the western side of the valley. It was first noticed by Professor James Hall, and by him described as follows in the *Third Annual Report of the Fourth Geological District:*[1]

At the last-named quarry I observed the singular fact of non-conformable strata, as yet the only instance noticed, and which various circumstances seem to render incredible. The strata are parts of the same mass, once continuous, the lower dipping south at an angle of four or five degrees, and the upper dipping north at about the same angle; and a short distance farther south the whole mass

[1] Albany, N. Y., 1839.

dips north. The only explanation that now offers is that at the time the rocks were subjected to the force which produced the undulations the upper part slipped over the lower and at this point partook of the elevation south, while the lower was affected only by the uplifting to the north.

It is not strange that Professor Hall should have failed to divine the cause of the stratigraphical disturbance since Pleistocene geology was then an undeciphered branch of the science. It is somewhat remarkable, however, that modern geologists have not commented upon this interesting phenomenon of the glacial invasion—interesting because it illustrates the great pressure sometimes exerted, and because it has a distinct bearing on that much-controverted theory of ice-erosion.

VALLEY DEPENDENCIES OF THE SCIOTO ILLINOIAN LOBE IN LICKING COUNTY, OHIO

FRANK CARNEY

Leverett classifies the drift of eastern Licking County as Illinoian. He says: The Illinoian deposits are much heavier in valleys than on uplands, and there is a marked sinuosity of margin to conform to the topographic conditions.[1] The observations described in this paper were undertaken in part to give closer definition to the extent of the topographic control to which Leverett refers. The paper attempts to show that the Scioto lobe on this part of its eastern margin, where it reached out over the more rugged topography of the coarser Mississippian and Pennsylvanian formations, was affected by valley dependencies. It is felt that a detailed study of the marginal areas may add to our knowledge of the exact shape of the ice-front at the time of its maximum extension.

MARGIN OF THE ILLINOIAN DRIFT

In central Ohio.—The general lobation of the Illinoian sheet, according to Leverett,[2] reflects the influence of great basins in the topography farther north, the Huron-Erie basin probably controlling its extension into the tract now drained by the Scioto River. That the extreme reach of the Illinoian ice in the southern part of the state—i. e., where it crosses the Ohio River in Brown County—is due to a combination of controls, seems likely.

Fig. 1 gives the results of Leverett's mapping of the Illinoian ice in Ohio. It appears that in one general locality on the eastern side of the Scioto lowland the ice manifested a tendency to protrude, as is shown by the curve southwest of Muskingum County; another evidence of this impulse is seen (Fig. 2), just north of this convexity, in the valley dependencies reaching beyond the body of the ice-field,

[1] *Glacial Formations of the Erie and Ohio Basins*, XLI Monograph, U. S. Geological Survey (1902), p. 222.

[2] *Ibid.*, p. 226.

described in the present paper. This later and more leisurely field-study gives greater prominence and exactness to this curve of local lobation first examined by Leverett.

In Licking County.—Save in the valleys, the Illinoian drift near its front is so attenuated that mapping it is a problem of elimination, or the careful study of the rather maturely dissected divide areas. The lesser details of topography in the marginal zone appear to have had slight influence on the outline of the ice-front, while obviously exercising a considerable control over the duration of the ice in its position

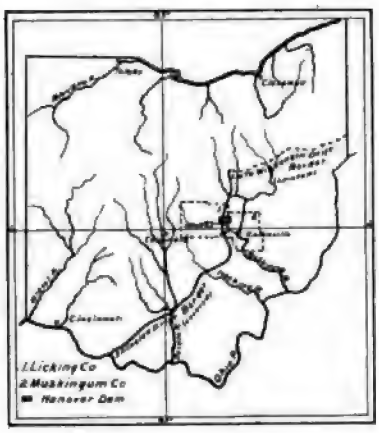


Fig. 1

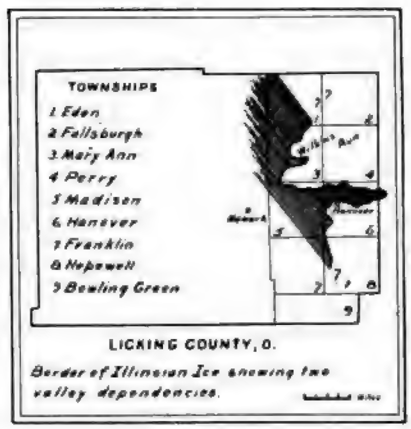
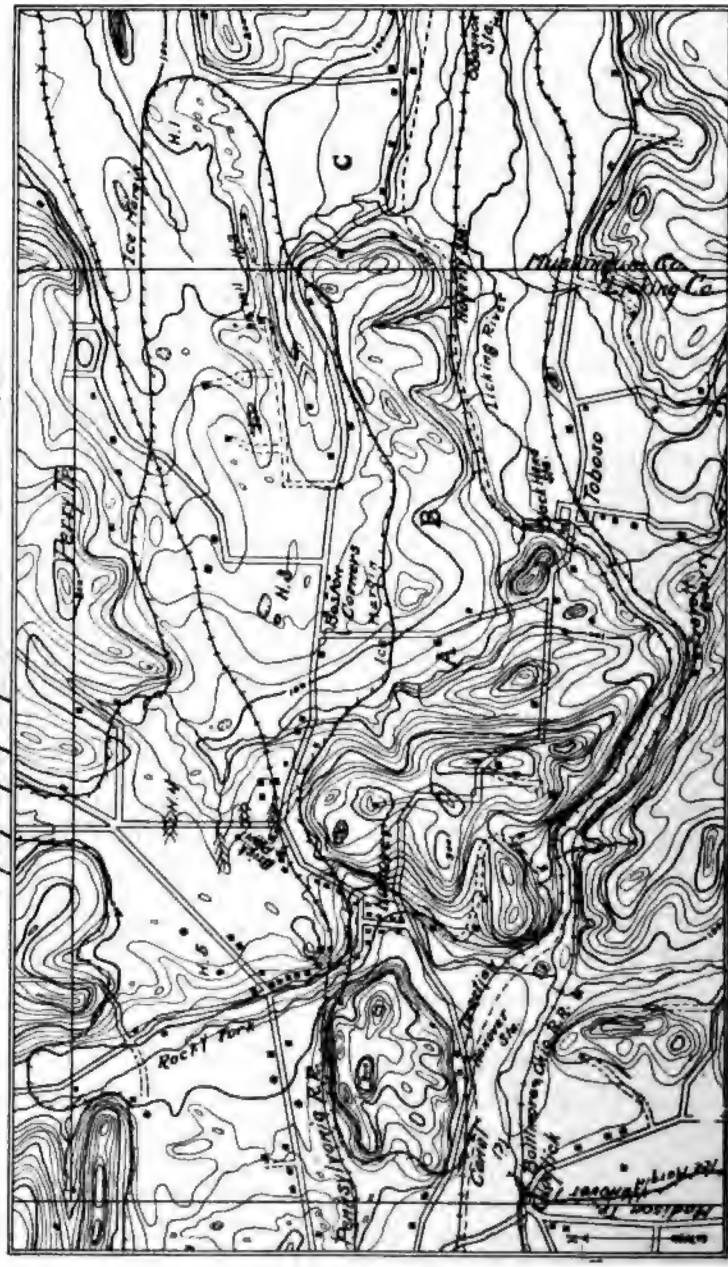


Fig 2

of maximum reach. This latter fact necessitates patient observation, particularly where the stratigraphy did not encourage differential-weathering effects previous to glaciation; it is evident that on slopes of heterogeneous rock structure facing the direction of ice-movement, benches of the more resistant formations, weathered into semi-detached spires and blocks,[1] would have suffered some from ice-work, even though the products of residual decay did not receive a noticeable admixture of glacial drift. But among the hills, where the rock structure is more uniform, and the weathered slopes correspondingly even, the absence of foreign material must be established before drawing the drift-line; and in these higher areas an unexpected localization of erratics surrounded completely by territory in which

[1] F. Carney, ***Bulletins of Denison University***, Vol. XIII (1906), p. 124.

Topography of Hanover Dam Area



Contour interval 20 feet—Datum is arbitrary Bench Mark at M.
⋙ Ice front channels — Fig. 8

the most diligent search has not revealed any evidence of glaciation is somewhat puzzling, but very convincing of the fact that the final demarkation of the glacial boundary is a problem of time.

In establishing the relationship of these valley dependencies of the Illinoian ice-sheet to the Scioto lobe, and in determining whether they are tongue-like extensions of the ice-mass at its period of greatest development, or at a later retreatal stage, three townships, Perry, Hanover, and Mary Ann, of Licking County, have been carefully

FIG. 4.—Looking south of east. The wooded area on the extreme left is rock, as is also the slope above the buildings on the right. The intervening ridge of drift marks the position of the ice-tongue that extended eastward from Wilkins Run.

studied, while like attention has been given to portions of adjacent townships. In valleys trending in general with the direction of ice-movement, the problem is one of distinguishing the unmodified drift from the deposits of entirely extra-glacial waters, and of determining the drift-covered portion of the valley walls.

It has been established that ice did not enter Perry township (Fig. 2) from the north or west,[1] and that the township was not glaciated

[1] F. Carney, *loc. cit.*, p. 124.

save for the presence of a lateral tongue reaching northward from the valley lobe that extended eastward into Muskingum County (Fig. 3).[1] Less than one-half of the next township west, Mary Ann, was covered by ice; this ice had a very irregular front. The conspicuous drift knolls at Wilkins Run are alluded to by Wright,[2] and by Leverett.[3] One of the most typical valley trains of this region was built into the mature valley southwest of Wilkins Run.

The southeast corner of Eden Township was not glaciated; but the front of the ice has not been traced in detail through this township, nor into Fallsburg. A small portion of the northeast corner of Madison Township was not covered by ice. The outline of the drift in Hanover Township is considered in the following section. Southward into Hopewell Township the margin of the ice has been traced in detail for only a short distance.

VALLEY DEPENDENCIES

At Wilkins Run.—A tongue of ice about one and seven-tenths miles long reached eastward from Wilkins Run. This village lies at one side of a mature valley which once embraced in its drainage the area east and north, the region now constituting the headwaters of the Rocky Fork; this defunct valley opened westward into the valley of the North Fork of the Licking River, and belonged to the ancient Newark River.[4]

[1] Since the government has not issued a map of this area, the writer, appreciating the difficulty that one not acquainted with the region would have in visualizing the topography described in the paper, has attempted to represent in contours the relief of the section about Hanover. No traverse work was done; county surveyor's maps were used for the highways and horizontal distances, an attempt being made to correct the grosser errors. It is felt, however, that the altitudes in reference to the arbitrary bench mark selected have been established with greater accuracy. For this purpose two aneroids were used; these instruments are of the same make, and for over a year have shown the same variation when together. During the progress of the field-work the aneroids were set the same at the bench each morning; the one kept at the bench was read every thirty minutes. The time at which readings were made on the other instrument in the field was recorded; the watchers were also set alike each morning. At night the field readings were corrected for the variations shown by the bench aneroid. Many critical points were checked several times.

[2] *The Glacial Boundary in Ohio*, Geological Survey of Ohio, Vol. V (1884), p. 755.

[3] *Loc. cit.*, p. 260.

[4] W. G. Tight, *Professional Paper No. 13*, U. S. Geological Survey (1903), p. 18.

This tongue-like extension of the ice pushed eastward to the point where the valley turns to the north; a tributary from the east which joins the major at its bend to the north, being in line with the feeding ice, was blocked also. The ice reached northward but a short distance beyond this angle; a few drift knolls mark this brief position. A halt of considerable duration was made after the ice had retreated to a position bringing the north side of the valley tongue directly across the valley; here it built a marginal ridge averaging 90 to 95

FIG. 5.—Moraine which marks the terminus of the Hanover valley dependency.

feet high, at no point lower than 70 feet, and about 500 feet broad at the base (Fig. 4). A terrace of similar development marks the outline of the ice against the walls of the valley elsewhere, except in front of the tributary valley, mentioned above, through which most of the drainage from the ice was led east to the Rocky Fork valley. It is evident that the Rocky Fork drainage had gained control of the mature valley long previous to its being occupied by this ice.

These moraine terraces, best developed on the south side of the valley, are very conspicuous. Commencing across the valley from

the hills mentioned by Wright,[1] a terrace of the aggradation type reaches half-way up the valley wall; it gradually descends eastward, where it becomes more irregular both because of initial distribution and of subsequent weathering. The line of demarkation between this drift and the upward slope is sharp.

The main body of ice, while the tongue reached eastward, maintained a position nearly north-south for a few miles each way from Wilkins Run. North of this place, so far as Mary Ann Township is concerned, the retreat of the ice-front appears to have been rapid, and there is no evidence that the valley lobe maintained intermediate positions; but the old valley becoming broader southwest of Wilkins Run encouraged a tongue-like extension of ice at the next halt of the ice-field; the well-developed valley train already mentioned was formed at this time.

At Hanover.—Here we have a much wider valley than the case just cited. The tongue of the ice reached about six miles eastward from the main body of ice. The maximum position of this valley dependency is marked by typical morainic topography (Fig. 5), with a contemporaneous deposition of drift against the side walls of the valley, which above the glacial débris are veneered with rock decay *in situ*. The line of demarkation between this drift and the valley wall is shown very conspicuously on the Hagerty farm southeast of the 216-foot well (Fig. 3). The drift, judged from surface appearance, especially east of the Muskingum County line, is rather bowldry; no very large bowlders were noted, but their fewness may be accounted for by the fact that the area has long been under cultivation.

This tongue-like extension of the ice maintained its distal position for some time, but in comparison with the duration of retreatal positions the period was proportionately brief. At the second halt the alignment of the drift suggests a tapering of the ice-tongue; this form, however, is not seen in the other halts (Fig. 3, *H*. 3, 4, etc.), because of the contraction that exists in the valley in the vicinity of Hanover. So long as the ice fed actively through this narrow part it broadened some in the wider segment of the valley beyond; only in this latter area should we expect to find evidence of tapering as the ice-movement weakened.

[1] *Loc. cit.*, p. 755.

Moreover, it should be noted that the distribution of the drift in this valley does not conform to the pattern usually normal to valleys[1] which encourage tongue-like extensions from the ice border in line with the direction of the deploying ice. The east-west valley passing Hanover is unusual in that it has a composite history, the most obvious feature of which, that it was formerly the course of a west-flowing stream, has been published.[2] The continuity of the south wall of the valley is broken by gaps at *A*, *B*, and *C* (Fig. 3), representing a change in the drainage-control of the region; the presence of these openings allowed free drainage, particularly in the case of *A* and *C*, from the southern side of the ice-tongue, thus removing much glacial rubbish that otherwise would have remained as a lateral terrace or ridge.

Furthermore, westward from Hanover the valley grows broader; at Newark, a distance of seven miles, it is about two miles between the rock walls. Consequently as the margin of the eastern side of the Scioto lobe assumed new positions in its decline—a long halt has been noted in the vicinity of Newark[3]—this valley dependency persisted.

The details of the drift south and southwest of Claylick have been studied for two miles, showing that the retreat of the main body of the ice was gradual, and apparently maintaining positions parallel to the convex margin mapped by Leverett.

SUMMARY

A study of the Illinoian drift in this broken topography of the coarser-textured and more resistant formations of the Mississippian and Pennsylvanian periods establishes the existence of tongue-like dependencies of the Scioto lobe reaching out into the eastward-trending valleys.

[1] R. S. Tarr, *Bulletins of the Geological Society of America*, Vol. XVI (1905), pp. 218, 219.

[2] F. Leverett, *loc. cit.*, p. 155; W. G. Tight, *Bulletins of Denison University*, Vol. VIII (1994), p. 47.

[3] F. Leverett, *loc. cit.*, Plate II.

Reviews

The Cause of Earthquakes, Mountain Formation and Kindred Phenomena Connected with the Physics of the Earth. By T. J. J. See. *Proc. Am. Phil. Soc.*, Vol. XLV (1907), pp. 274–414.

The typical propositions of this paper are the following:

The dynamical cause of earthquakes and volcanoes probably depends upon the explosive power of steam formed within or just beneath the heated rocks of the earth's crust chiefly by the leakage of the ocean beds. (Pp. 276, 277.)

The internal temperature of the earth is extremely high, with heated rocks quite near the surface, while the crust is fractured and leaky everywhere, and especially where the depth of the sea is greatest. The sea covers three-fourths of the earth's surface, and earthquakes are found to be most violent where the sea is deepest, and volcanoes most numerous on the adjacent shores. Could then anything be more probable than to suppose that both of these great natural phenomena depend simply and wholly upon the explosive power of steam which has developed in the heated rock of the earth's crust? (Pp. 278–80.)

The conclusions are as follows, from which the geologist who has some accurate knowledge of earthquakes, volcanoes, mountains, and geophysics may decide whether he cares to follow up these views in the paper itself:

1. We have seen that deposits of sediment on the continental shelves could not possibly produce anything but the most gradual increase of weight on these portions of the earth's crust; and since such rocks as marble are proved to be fluids of great viscosity, and therefore capable of slow secular bending without rupture, we may feel sure that any stresses thus arising in the earth's crust would be relieved by gradual yielding, and that no violent earthquake shock could ever arise from such a cause.

2. The theory that earthquakes are due to fracture and slipping of rocks is disproved by the great depth (ten to twenty miles) at which world-shaking earthquakes are found to originate, and by virtue of the fact that they come not from a point nor from a line, but from an area; and moreover earthquakes follow the seashore, seldom occurring far inland, and never in desert countries, though abundant in the bed of the ocean.

3. It therefore follows that earthquakes must depend upon explosive forces within or just under the earth's crust, and frequently spread over a considerable area, and the preponderance of disturbances in the sea along the shores of continents shows that the forces depend in some way upon the sea water. These explosive forces can be best studied in connection with the eruption of volcanoes,

since volcanic outbreaks are also accompanied by earthquakes often felt over large areas.

4. Not all earthquakes lead to eruptions, but if the shocks in a given region cease on the eruption of a neighboring volcano, we may feel sure that the forces producing the eruption also produced the antecedent earthquake shocks felt by the surrounding country.

5. That steam is the cause of volcanic eruptions is proved by the distribution of active volcanoes about the seashores and by the innumerable eruptions which occur in the depths of the ocean, whereas such vents always die out inland; and moreover by the fact that of the vapors emitted from volcanoes 999 parts in 1,000 is estimated to be steam, the remaining one-thousandth part being by-products incidental to the moisture and high temperature.

6. The *vera causa* of volcanic action and of certain earthquakes thus established for some particular cases must be held to be the universal cause in all cases whatsoever, according to Newton's rule of philosophy.

7. The heaving of steam accumulating within or just beneath the earth's crust is therefore the true cause of all world-shaking earthquakes, and volcanic outbreaks occur only when an outlet is forced through to the surface, which usually happens in mountains, where the earth's crust is already badly fractured and upheaved.

8. When the subterranean steam pressure becomes great enough to shake the earth's crust, it naturally moves at the nearest fault line, where the rocks are broken, *but the movement observed is the result, not the cause of the earthquake.*

9. Volcanoes are particular mountains blown open by steam pressure under the throes of earthquakes (cracks in the rocks appear to be the beginning of some few volcanoes), and since all volcanoes blow out pumice and ashes, these materials must be held to exist in all mountains, and are made by the inflation of molten rock with steam and other vapors.

10. Any mountain peak, therefore, is capable of becoming a volcano if the subterranean steam pressure be sufficiently powerful to break open an orifice. But orifices close up and volcanoes die out inland and elsewhere if the supply of steam is inadequate to keep open the vents upon which the activity depends. Even if stopped up for a time, later heaving of the earth may give the volcano renewed activity, and when the mountain has been dormant for a long time it is found that the violence of the eruption is greatly increased. The violence of the subterranean pressure in such a case approaches that of a region which has no vent at all, and hence we see why earthquakes in non-volcanic regions frequently become so terrible, because the forces accumulate to frightful fury before any relief whatever is afforded, and the result is a most terrible earthquake.

11. The mountains are formed by the injection of steam-saturated lava under the coast, which breaks the overlying surface rocks and gives rise to a ridge parallel to the sea. This is why all mountains are formed parallel to the seashores.

12. By continually injecting the land with lava from under the bed of the sea the coast is raised and the mountains upheaved, and some of them usually break out into volcanoes; while at the same time the support of the sea bottom is undermined by the thinning-out of the fluid substratum, and at intervals the bottom sinks down to restore stability.

13. The sinking of the sea bottom in this natural process of earthquake injection of the land is the cause of that class of sea waves found to follow violent earthquakes, in which the water first withdraws from the shore and then returns as a huge wave. Those waves noticed to rise suddenly without previous recession of the water usually are due to submarine upheavals and eruptions in the bed of the sea.

14. Islands are built up by injection from the sea, and hence have their mountains as veritable backbones, because the injection is symmetrical from both sides. In many cases the sea bottom is thus undermined and finally sinks down, making a hole beside the island, or a trench. The fact that all islands are not accompanied by such sinks is no argument against the theory, because the subsidence has not always taken place; it is the occurrence of even a considerable number of such sinks beside islands which proves the validity of the theory. Such intimate associations between elevation and depression could not be the result of chance.

15. In the repair of ocean cables broken by earthquakes, subsidence of the sea bottom is frequently found to follow these disturbances. This is a direct observation of the above effects in certain cases which are established by actual measurement, the subsidences frequently amounting to hundreds of fathoms.

16. The sea bottom does not subside without the lava under the crust being forced out into some other place, as into islands, submarine ridges, or shores; none of this movement is due to the secular cooling of the earth, but is all to be explained by the undermining effect of steam accumulating under the earth's crust.

17. Mountains in the interior of a dry country, as the Rocky Mountains in Colorado, exhibit no important movements, while those on the coast, like the Andes, are always heaving. This shows that the sea is the cause, and not the secular cooling of the globe, which is wholly insensible.

18. The only countries which are free from earthquakes are the deserts, and therefore practically uninhabitable; there is accordingly no escape from earthquakes, and buildings designed for permanency should be framed to withstand them without material injury.

19. While in the long run the elevation of the land predominates, there is also subsidence, due to the non-occurrence of the forces in certain regions beneath the crust. It is idle to deny these oscillatory movements of the crust, and many good illustrations of both are clearly established. Every island which is thrown up in the sea is a witness to one of the most general laws of nature.

20. As water is taken up in the crust both in the crystallization of rocks and

in the processes of earthquake movements, and only a part of this vapor is restored to the surface through volcanic action, there is a secular desiccation of the oceans, but the process is excessively slow and not certainly recognizable during the historical period, though a part of the lowering of the strand line in later geological ages is no doubt traceable to this cause.

21. The elevation of the plateaus depends on the same cause which upheaved the mountains; and all plateaus, like the mountains, are underlaid with various forms of pumice, which accounts for their feeble attraction as shown by geodetic observations.

22. No doubt various chemical changes go on under the earth's crust where the water has penetrated the lava and the steam becomes superheated, but the predominance of water vapor in volcanoes shows that the other gases are only by-products, incidental to the moisture and great heat. Dissociation of water vapor is one of these effects.

23. The details of mountain structure admit of explanation on the present hypothesis, while heretofore no such explanation was forthcoming. A theory which accounts for the position of the ranges relatively to the sea, the slopes of the ranges, and the side spurs, and the relation of mountains to earthquakes and volcanic phenomena, should have a strong claim to acceptance. This theory was partially foreshadowed by the Arabian astronomer Avicenna, in the tenth century of our era.

24. The theory of the penetration of sea water into the crust of the earth and its connection with volcanoes and earthquakes dates back to Lucretius and Aristotle, while the upheaval of the land is distinctly announced by Strabo. We have, therefore, been simply verifying and extending the impressions of the ancients formed from the general aspects of nature long before the sciences had become exact. (Pp. 403–7.)

It is only fair to Avicenna, Lucretius, Aristotle, Strabo, and other distinguished authors quoted in this paper, to remark that they are not to be held responsible for all of the assertions of putative fact and physics with which their views are associated in this paper.

T. C. C.

---

1. *Some Additions to the Carboniferous Terrestrial Arthropod Fauna of Illinois*. By A. L. MELANDER. (*Journal of Geology*, Vol. XI, No. 2, February–March, 1903, pp. 178–98, Plates V–VII.)
2. *Some New Structural Characters of Paleozoic Cockroaches*. By E. H. SELLARDS. (*American Journal of Science*, Vol. XV, April, 1903, pp. 307–15, Plates VII, VIII.)
3. *Discovery of Fossil Insects in the Permian of Kansas*. By. E. H. SELLARDS. (*Ibid.*, Vol. XVI, October, 1903, pp. 323–324.)

4. *Zur Phylogenie der Hexapoden.* By ANTON HANDLIRSCH. (*Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften in Wien,* Mathematisch-naturwissenschaftliche Klasse, Vol. CXII, 1903, pp.1–23.)
5. *Eine neue Blattinaria aus der Oberen Steinkohlenformation* (Ottweiler Schichten, Rheinpreussen). By FERNAND MEUNIER. (*Jahrbuch der Königlichen Preussischen Geologischen Landesanstalt und Bergakademie,* Vol. XXIV, No. 3, 1903, pp. 454–57, Plate XVIII.) (1904)
6. *Les insectes houillers de la Belgique.* By ANTON HANDLIRSCH. (*Mémoires du Musée royal d'Histoire naturelle de Belgique,* Vol. III, 1904, pp. 1–18, Plates I–VII.)
7. *Über einige Insektenreste aus der Permformation Russlands.* By ANTON HANDLIRSCH. (*Mémoires de L'Académie impériale des Sciences de St-Pétersbourg,* Série 8, Classe physico-mathématique, Vol. XVI, No. 5, 1904, pp. 1–7, with one plate.)
8. *A Study of the Structure of Paleozoic Cockroaches with Description of New Forms from the Coal Measures.* By E. H. SELLARDS. (*American Journal of Science,* Vol. XVIII, August–September, 1904, pp. 113–34, and 213–27, Plate I and 37 text figures.)
9. *Un Nouvel Insecte Fossile du Carbonifère de Commentry.* By AL. N. AGNUS. (Rev. Scientifique du Bourbonnais et du Centre de la France, Feb.–March, 1904, pp. 39–43; with one text figure.)
10. *Palæoblattina douvillei Brongnt.* By AL. N. ANGUS. (*Ibid,* April, 1904, pp. 85–86.)
11. *Revision of American Paleozoic Insects.* By ANTON HANDLIRSCH. Introduction by CHARLES SCHUCHERT; translated by LUCY P. BUSH. (*Proceedings of the U. S. National Museum,* Vol. XXIX, 1906, pp. 661–820.)
12. *Die fossilen Insecten und die Phylogenie der recenten Formen.* By ANTON HANDLIRSCH. Lieferungen I–IV, with 36 plates. Leipzig: Wilhelm Engelmann.
13. *Types of Permian Insects .* By E. H. SELLARDS. Part I, Odonata. (*American Journal of Science,* Vol. XXII, September, 1906, pp. 249–58; text figures 1–8.)

14. *Geological History of Cockroaches.* By E. H. SELLARDS. (*Popular Science Monthly*, March, 1906, pp. 244–50.)

15. *Haben die Paleozoischen Blattiden im Hinterflügel ein Praecostalfeld?* By DIETRICH V. SCHLECHTENDAL. (*Zeitschrift für wissenschaftliche Insektenbiologie*, Vol. II, March, 1906, pp. 47–50.)

16. *The Wing Veins of Insects.* By C. W. WOODWORTH. (*Technical Bulletins*, California Agricultural Experiment Station, Vol. I, 1906, pp. 1–152.)

1–5. Melander's paper is largely systematic. Two new genera of Hexopoda are described, *Petromartus* and *Protodictyon*, and one new genus of Arachnoidea, *Hadrachne*. The arachnid and insect material from the Carboniferous of Illinois contained in the Walker Museum of the University of Chicago, including two specimens from the Chicago Academy of Science, is identified and listed, and the type specimens are indicated. The classification of insects proposed by Scudder is followed. Sellards identifies the fossils previously known as *Dipeltis*, and referred by Packard and others to the Crustacea, as the nymph stages of cockroaches, and gives also a description of additional nymph and adult cockroaches, including a new genus of very large cockroaches, *Megablattina* (Sellards, non Brongniart; changed later to *Archoblattina*). The presence of an ovipositor is recognized on certain fossils identified as nymph cockroaches. The second paper by Sellards reports the discovery of insects in the Kansas Permian. The comparatively rare occurrence of insects in the Permian deposits is mentioned. The lack of definite record of insects from deposits older than the Carboniferous is noted. Handlirsch's paper is concerned with the Hexopoda in general, and proposes a revised classification for the group as a whole. The Hexopoda in this classification fall into four classes: Collembola, Campodeoidea, Thysanura, and Pterygogenea. Thirty-four orders are recognized, twenty-eight of which (grouped under eleven subclasses) are referred to the Pterygogenea. The Paleozoic insects are passed in review, and their place in the proposed classification, is indicated. Meunier gives a description of a new Coal Measure cockroach referred to the genus *Etoblattina* (*E. pygmaea* n. sp.).

6–10. The insects known from the Coal Measures of Belgium are referred by Handlirsch to fifteen genera, twelve of which are described as new. The insects described are regarded as representative of four orders, three of which—Paleodictyoptera, Megasecoptera, and Protorthroptera—are exclusively Paleozoic, while the fourth, Blattoidea, continues to the present. Eleven genera of insects are recognized from the Russian Per-

mian, nine of which are described as new. Three genera are referred to the Ephemerids, and one doubtfully to the Perlidae. The group Paleohemiptera is proposed for two genera, *Presbole* and *Scytinoptera*, regarded as ancestral to the Hemiptera. Mantidae-like forms are represented by the genera *Paleomantis* and *Petromantis;* the Blattoidea are represented by two genera, *Limmatoblatta* and *Aissoblatta*. Sellards regards the Paleozoic, Mesozoic, and modern cockroaches as making up a group of superfamily rank under the order Orthoptera, for which the term "Blattacea" is proposed. The body and wing structure of Paleozoic cockroaches is described, and the lines of specialization are discussed. In the first of the papers listed Angus described a new cockroach, *Etoblattina Gaudryi*, of which one hind wing, lacking the anal area, and the two front wings are preserved. The second paper by this author records a reexamination of the supposed Silurian fossil insect. *Palæoblattina Douvillei*, with the conclusion that this fossil does not represent an insect but pertains to the trilobites, and is in fact a part of the genal angle of one of the Asaphidæ.

11–16. Nine orders are regarded by Handlirsch as present in the American Paleozoic, as follows: Palædictyoptera, Protodonata, Megasecoptera, Hadentomoidea (new order), Hapalopteroidea (new order) Mixotermitoidea (new order) Protorthroptera, Protoblattoidea (new order,) and Blattoidea. Of these the first eight are regarded as being replaced in later deposits by other orders, the Blattoidea alone having continued to the present time. Twenty-five genera are referred to the Paleodictyoptera, seventeen of which are new. Two Protodonate genera are recognized from the American Carboniferous, *Paralogus* Scudder and a new genus, *Palætherates*. Two American genera, *Rhaphidiopsis* Scudder and *Adiaphtharsia* gn. n, are referred to the order Megasecoptera. The new order Hadentomoidea is based upon a single specimen, *Hadentomum americanum gn. sp. n*, from the collection of Mr. Daniels. The new order Hapalopteroidea includes but one American specimen, of which one front wing only is known. The provisional new order Mixotermitoidea is based upon two genera, *Mixotermes* from Saxony and *Geroneura* from New Brunswick. The Protorthoptera embrace a series of forms transitional between the Palædictyoptera and the Orthoptera. Sixteen genera are referred to this order. The Protoblattoidea are considered transitional between the Palædictyoptera and the Blattoidea. Thirteen genera are referred to this order. An entirely new grouping of the cockroaches is adopted. The Paleozoic representatives of this order are grouped into eleven families, ten of which are here established as new. Eighty-nine genera are recognized, sixty-nine of which are described as new. A table

prepared by Mr. David White accompanies the paper, showing the geological horizon as determined by paleo-botany and stratigraphy of the insect-bearing localities of the American Carboniferous.

"Die Fossilen Insekten," the second title of this year by Handlirsch, is intended to serve as "Ein Handbuch für Paleontologen und Zoologen." The fossil insects are treated chronologically by periods. No insects are recognized from deposits older than the Upper Carboniferous. The introductory part of the publication contains a synopsis of the orders of recent insecta. The Carboniferous insects are described in parts I, II, and III to p. 343. Permian insects follow (pp. 344 to 393). Mesozoic insects occupy the remainder of part III and IV. The remaining parts to be issued will complete the treatment of Mesozoic and Cenozoic forms in order. All known fossil Hexopoda are to be included in this work, and the described specimens so far as possible illustrated.

Sellard's paper on Odonata is Part I of a paper discussing the leading types of Permian insects. A new genus of Odonates, the first of this group obtained from the Permian, is described. The conclusions reached from a study of the Permian Odonates, and from a comparison of these with the Coal Measure forms, are that the wing venation of Paleozoic dragon-flies is not fundamentally different from that of modern dragon flies, as believed by Scudder, and that the Paleozoic dragon-flies are not to be separated as an order from Mezozoic and modern dragon-flies, as is done by Handlirsch, Three suborders are recognized for the order Odonata; Protodonata. Zygoptera, and Anisoptera. The second paper by Sellards is a résumé of the geological history of the cockroaches. Von Schlechtendal regards the vein in the hind wing of certain Coal Measure cockroaches, interpreted by Sellards as the costa, as being in reality the subcosta. Woodworth's paper on the wing veins of insects contains critical remarks on the venation of the wings of the better-known families of Paleozoic insects.

E. H. SELLARDS

The Place of Origin of the Moon—The Volcanic Problem. By WILLIAM H. PICKERING. *Journal of Geology*, Vol. XV, January–February, 1907, pp. 22–38.

To many geologists the arguments of this paper will appear to need no refutation and, if published in any other than a leading geological periodical, would not call for comment. There is danger, however, that by not formally presenting the contrary side of an argument, a greater credit and authority may be given to certain views by those in other branches of science than is warranted. It is because this article is of a nature which

may lead to its being widely quoted by those not pretending to pass independent judgment upon the problem, that the following reply is written.

In 1879 Professor George H. Darwin gave cogent reasons for thinking that originally the moon was much nearer to the earth than it is at present, and considered it probable that the earth and moon at one time constituted a single mass, though this conclusion was admittedly in the nature of an inference from the preceding. As Professor Pickering states, this conclusion has been accepted by the great majority of astronomers, although many of the geologists do not view it with favor. Accepting this hypothesis as to the origin of the moon, the author states:

> When the Earth-Moon planet condensed from the original nebula, its denser materials collected at the lower levels, while the lighter ones were distributed with considerable uniformity over its surface. At the present day, we find the lighter materials missing from one hemisphere. The mean surface density of the continents is about 2.7. Their mean density is certainly greater. We find a large mass of material now up in the sky, which it is generally believed by astronomers formerly formed part of our Earth, and the density of this material, after some compression by its own gravity, we find to be 3.4, or not far from that of the missing continents. From this we conclude that this mass of material formerly covered that part of the Earth where the continents are lacking, and which is now occupied by the Pacific Ocean. In fact, there is no other place from which it could have come.
>
> Who it was that first suggested that the Moon originated in the Pacific is unknown. The idea seems to be a very old one. The object of the present paper is to find what support for this hypothesis is afforded by the results of modern science, when examined both qualitatively and quantitatively. (P. 30.)

All will agree that the hypothesis is a very interesting one and worthy of the space given to it, and, even if opposed by very strong objections, is still of value as a hypothesis in the absence of positive knowledge as to the age and ultimate origin of the ocean basins. It must be concluded, however, as shown in these two paragraphs as well as many others in the article, that the author has not only failed to look up and to give credit to the originator of the hypothesis, which is here duplicated in many details, but has treated many phases of the subject with a positiveness and superficiality which cannot commend themselves to careful students of the subject. This is in marked contrast to the cautious treatment of the hypothesis by its originator, Osmund Fisher, in his initial statement of it entitled, "On the Physical Cause of the Ocean Basins," *Nature*, Vol. XXV (1882), p. 243, or in his reprint of it as A Speculation on the Origin of Ocean Basins, chap. xxv, *Physics of the Earth's Crust*, pp. 336–41, 379–81 (second edition, 1889).

The hypothesis appeals to the imagination, and at first thought appears to offer a striking explanation of both the shape and depth of the ocean basins. There are, however, certain assumptions involved in this restatement of it which are not clearly indicated as such, and the difficulties are dismissed without serious treatment. It is to call attention to these, as well as to give credit to the original papers on the subject, that this review and criticism is written.

First, no discussion is given of the possibility that the interior density of the earth may be largely due to the gravitational compression of ordinary rock material, since Professor Pickering states:

> The specific gravity of the Earth as a whole is 5.6. That of the surface material ranges in general between 2.2 and 3.2, with an average of 2.7. The specific gravity of the Moon is 3.4. This indicates clearly that the Moon is composed of material scraped off from the outer surface of the Earth, rather than of matter obtained from a considerable depth. At the same time, the specific gravity 3.4 indicates that the layer of material removed had an appreciable thickness. (P. 24.)

Nothing is really known as to the limits of the compressibility of rock under pressures of millions of pounds per square inch, allowing the alternative hypothesis to be equally assumed, that the earth may be largely made up of material which would not have a specific gravity of much, if any, over 3, if free from subcrustal pressures. Following this assumption, the moon may have been abstracted from any part of that mass, and at any time before the present relation of heavier oceanic and lighter continental crustal segments originated. The continents may then have subsequently come into existence according to any one of a number of hypotheses, such as proposed by Chamberlin or others. As the moon's mass is but one eighty-first that of the earth, its radius but a fourth, and gravity at its surface but one-sixth, it is seen that the material of the moon would suffer comparatively little compression even in its deeper parts, while its outer parts may consist of highly cellular rocks.

Second, this hypothesis rests upon the doctrine of the perpetual existence of the present forms and relations of the continental platforms. This is passed over with the statement that "it is the general opinion among geologists that the continental forms have always existed—that they are indestructible" (p. 28).

From the early advocacy of J. D. Dana, this may be called an American view, and represented a wholesome return from previous untrammeled speculations regarding the interchangeability of ocean basins and continental platforms. That Dana himself, however, came to a belief in a

liberal interpretation of this doctrine might have been easily determined by consulting the last edition of his manual (pp. 737, 1019), where it is seen that he accepts, as probable, former extensions of land in the Southern Hemisphere by which all of the now isolated land masses were connected. That a present belief in the strict permanence of the continental outlines is not shared by many geologists, especially by Europeans, is indicated by the paleogeographic maps in many books and articles, among which may be singled out the *Traité de Géologie* by A. de Lapparent (1911 pages; fourth edition, 1900).

Such maps are largely based upon paleontological evidence from many groups of animals and plants, and consequently appeal most strongly to the paleontologist, but that there is structural evidence for the view of former extensions of the continental platforms beyond their present limits may be gleaned from the monumental work of Suess, *Das Antlitz der Erde.*

In view of these statements, it may be said that it is the opinion of many well-qualified geologists that, while no large areas of oceanic basins have been uplifted and added to the continental platforms, there has been, on the contrary, an intermittent but progressive continental fragmentatation through geological time by which land masses, most notably Antarctica, have been isolated and reduced in size, and the area of the oceanic basins correspondingly increased. The consequent enlargement of volume of those basins has tended to drain the shallow seas from the continental platforms and cause an intermittent but progressive emergence of the lands. Relative vertical movements of the oceanic segments and erosion of the lands have, however, also been major factors further complicating the result. The only known limitations to such changes of continental relations appear to be given by the general maintenance through geological time of the critical relations of the sea-level to the continental surfaces, and if, as seems probable, the volume of sea-water has increased through time, the area of the continental ptalforms may, in somewhat like measure, have decreased. These views affect the present hypothesis of the place of origin of the moon in two ways: by indicating that the Atlantic and Pacific may not always have possessed their present forms; but further, and more importantly, that the causes of the existence of ocean basins and continental platforms are not to be found alone in a primal cause no longer acting, but, to a considerable extent at least, to still acting and persistent causes.

Interesting consequences of certain suggestions put forth may be seen by comparing the last paragraphs on pages 32 and 33 respectively. The logical conclusion from these is that the ocean basins, formed by the break-

ing away of the moon, may not have existed until the end of the Paleozoic, with the result that, granting the present volume of sea-water, a universal ocean, averaging 10,400 feet deep, previously covered the whole earth. How, under such conditions, there came to be any sediments in the Appalachian geosyncline from a land "of continental proportions" the author does not attempt to explain.

Again, on page 31, the basic nature of the Hawaiian lavas is explained as a consequence of the removal of the lighter acid crust from the ocean basins to make the moon. It is easy to see how on this hypothesis the author would account for the enormous basaltic outpourings which have taken place over the surface of the continents, but it would be interesting to have his explanation of the fact that in Washington's tables of chemical analyses of igneous rocks the only analysis reported from Kerguelen Island gives a phonolite with 58.2 per cent. of silica and 12.0 of alkalies; the only one from Gough's Island a trachyte obsidian with 61.2 per cent. silica and 12.4 of alkalies; the only two from Ascension Island are trachyte and obsidian, the former with 71.0 per cent. of silica, the latter with 72.7.

The second part of the article, entitled "The Volcanic Problem," does not seem to have any very clear or close relation to the first part on the "Place of Origin of the Moon."

JOSEPH BARRELL

Essentials of Crystallography. By E. H. KRAUS. Ann Arbor, Mich.: Geo. Wahr. Pp. x+162; 427 figs. in text.

In the words of the preface, this book is "intended for beginners and aims to present the essential features of geometrical crystallography from a standpoint which combines the ideas of symmetry with those of holohedrism, hemihedrism, etc." All the possible crystal forms are discussed with the important classes pointed out.

A bibliography of forty-one titles of important reference books and articles is at the beginning of the book. This is followed by a sixteen-page general discussion of the properties of crystals, their arrangement into systems, the symbols used, the symmetry, and fractional forms. The systems are then taken up in order, beginning with the cubic and following through to the triclinic. The relations of axes, symmetry, and possible classes are taken up with considerable care in each system.

Compound crystals, with a full discussion of the laws of twinning, forms the last chapter, and is followed by a concise tabular classification of the classes, showing at a glance the planes, axes, and centers of symmetry, the possible forms, and the representatives, when known, of each class.

All of the illustrations are in orthographic projection, crystal projections being purposely omitted. The relations of the classes in each system are well brought out by tables and diagrams. The systems of notation of Weiss, Naumann, and Miller are used throughout the book in parallel columns, giving at a glance the relations between them. The classification of Groth is followed in the reverse order.

The book seems well suited to its purpose, and puts in a concise and compact form that part of its subject which is absolutely essential for an understanding of crystallography.

J. C. J.

Das Berneroberland und Nachbargebiete, specieller Theil. By A. BALTZER. Berlin: Borntraeger. Pp. 330, with 74 figures, and a map of the routes.

A series of European geological guidebooks is now being published by the Gebrüder Borntraeger in Berlin. Ten of these, devoted to the Elbe valley near Dresden, Mecklenburg, Bornholm, Pomerania, Alsace, Riesengebirge, Schonen, Campania, Italian Alps, and the Alps of Eastern Switzerland, are already out. The latest guide, that of the Bernese Oberland, is in two volumes, the first of which, describing special detailed routes, has recently appeared; the second volume, devoted to more general topics, including stratigraphy, formation of the mountains in general, a section upon the modern tectonics, the Aarmassiv, and the diluvial Aargletscher, is soon to follow. The chief attraction of this work lies in the field of tectonics, and as this obtrudes itself upon the traveler, it is here brought into the foreground and explained by the aid of profile sections. Long lists of rocks and minerals which may be studied to better advantage in museum collections are here avoided.

The general plan of the booklet is to follow one principal route through the Bernese Oberland proper, from which there are numerous side excursions to points of interest near the main lines of travel. In addition there are three supplementary routes from the Oberland to Lake Lucerne, by the Brünig, Susten, and Furca passes, in the last of which the St. Gotthard region is included.

The first chapter treats of that model of folded mountain structure, the Bernese Jura, than which there is no better introduction to the tectonics of the Alps. Following this are placed the regions intermediate between the Jura and the high Alps—Bern, the Lake of Thun, and Interlaken. In the Oberland proper the route visits in succession the well-known centers of attraction, Mürren, Wengern Alp, Grindelwald, Meiringen,

Grimsel Pass, Eggishorn, and Belalp—a circular tour around the great peaks of this group. Succeeding chapters describe the points of geologic interest from the Rhone valley to Bern by way of Kandersteg and Spiez and of the western portion of the range as far as Lake Geneva. In this itinerary the excursions have been planned for the pedestrian rather than the mountain climber, and by selecting various readily accessible view-points much of the wilds of the range can be studied without the labor and difficulties involved in penetrating into the heart of the mountains.

The booklet is well illustrated with many profiles of structure, numerous photographs and sketches, and a map of the route. Being almost identical in size with Baedeker's *Switzerland*, it fits readily into a coat pocket. At the end is a summary of the geologic literature bearing upon this portion of the Alpine chain.

R. T. C.

Guide to the Geology and Paleontology of the Schoharie Valley in Eastern New York. By AMADEUS W. GRABAU. (New York State Museum, *Bulletin No. 92*, 1906.) Pp. 75–387, 24 plates, 225 figures and geologic map.

The Schoharie Valley is a classic locality in the history of American stratigraphic geology, since in it and Albany County the first systematic study of the Paleozoic rocks of New York was begun. In this valley, near Schoharie village, lived the Gebhards, father and son, who between 1820 and 1835 worked out the succession of Silurian and Devonian strata in that region, collected fossils, and proposed stratigraphic names some of which, as, for example, Pentamerus and Tentaculite limestones, are still familiar to geologists.

As the title indicates, this work is designed as a guide to the geology and paleontology of the Schoharie Valley for the use of students and others interested in its fine stratigraphic sections, for which it has long been famous. Naturally, therefore, the stratigraphy of the Schoharie region is minutely described, four chapters, comprising 150 pages of the *Bulletin*, being devoted to it. In these chapters the nineteen geological stages of that region, which range from the Lorraine of the Lower Silurian to the Catskill of the Upper Devonian, are fully described, together with the more characteristic fossils which are figured.

Chapters 5 and 6 are devoted to a description of characteristic sections in the Schoharie region and the Helderbergs, and Dr. Grabau has not confined himself simply to the sections which he has studied, but has quoted freely from the works of former students. It should also be stated that

he has fully credited the material derived from such sources, which is in marked contrast to the custom of some other geologists who have in recent years published descriptions of sections located in this area. While these chapters will not be so popular with the general reader, for the student of ability they will, perhaps, prove the most valuable of the entire book. Chapter 7 contains lists of fossils found in the various formations of the Schoharie region which have, in part, been compiled from the lists of earlier geologists. The next chapter, which is devoted to the physiography, gives an account of Howe's and Ball's caves. The ninth and final chapter considers the Schoharie region in its relation to man, and gives a full account of the formations or deposits of economic value. At the close of the work is an eight-page glossary of technical terms. The book is profusely illustrated by excellent plates of geological scenery, numerous figures of geological structure and fossils. A pocket contains a geologic map of the Schoharie and Cobleskill Valleys, on which are represented the following thirteen geological divisions, listed in ascending order, viz.: Lorraine shale, of Lower Silurian age; Brayman shale, Cobleskill dolomite, Manlius and Rondout dolomite and limestone, of Upper Silurian age; Coeymans limestone, New Scotland shale, Becraft limestone, Oriskany quartzite, Esopus grit, Schoharie grit, and Onondaga limestone, of Lower Devonian age; and the Marcellus shale and Hamilton formation, of Middle Devonian age. It will be readily seen that there is a long list of formations available for study which in the high and steep hills bordering the Schoharie Valley and in the Helderberg escarpment are admirably exposed.

The early work of Eaton in Albany County and of the Gebhards in the Schoharie Valley brought to the Helderbergs and the valley at an early date such famous geologists as Lyell, James Hall, and Louis Agassiz. In later years other professors from Harvard, Yale, Columbia, Cornell, Union, and other institutions have brought their students to this beautiful and classic ground. Now with this admirable *Guide* at hand this region should become a veritable Mecca for geologists. Students of the science are certainly under great obligations to Dr. Grabau for the preparation of this excellent handbook, and to Dr. John M. Clarke, New York's efficient and scholarly state geologist, for its publication in a most attractive and interesting form.

C. S. Prosser

RECENT PUBLICATIONS

—Academy of Science and Letters of Sioux City, Iowa, for 1905–6, Proceedings of the. Volume II. [Sioux City, 1906.]

—AGASSIZ, A. Report of the National Academy of Sciences for the Year 1905. [Washington, 1906.]

——Reports on the Scientific Results of the Expedition to the Eastern Tropical Pacific, in Charge of Alexander Agassiz, by the U. S. Fish Commission Steamer "Albatross," from October, 1904, to March, 1905, Lieut.-Commander L. M. Garrett, U. S. N., Commanding. V. General Report of the Expedition. [Memoirs of the Museum of Comparative Zoölogy at Harvard College. Vol. XXXIII. Cambridge, 1906.]

—American Institute of Mining Engineers, Transactions of the. Vol. XXXVI. Containing the Papers and Discussions of 1905. [New York City, 1906.]

—AMI, H. M. Bibliography of Canadian Geology and Palæontology for the Year 1905. [From the Transactions of the Royal Society of Canada, Second Series, 1906–7, Volume XII, Section IV, Geological and Biological Sciences. Ottawa, 1906.]

—ANDREWS, B.A., E. C. Molybdenum. [Department of Mines and Agriculture, Geological Survey, New South Wales, Mineral Resources, No. 11. Sydney, 1906.]

—ARNOLD, R. Geological Reconnaisance of the Coast of the Olympic Peninsula, Washington. [Bulletin of the Geological Society of America, Vol. XVII, pp. 451–68, Pls. 55–58. Rochester, September, 1906.]

———The Tertiary and Quaternary Pectens of California. Department of the Interior, U. S. Geological Survey, Professional Paper No. 47, Series C, Systematic Geology and Paleontology, 76. Washington, 1906.]

—ASHLEY, G. H., and GLENN, L. C. Geology and Mineral Resources of Part of the Cumberland Gap Coal Field, Kentucky. [U. S. Geological Survey, Professional Paper No. 49; Series A, Economic Geology, 64; Series B, Descriptive Geology, 78. Washington, 1906.]

—BAKER, F. C. A Catalogue of the Mollusca of Illinois. [Bulletin of the Illinois State Laboratory of Natural History, Vol. VII, article vi. Urbana, September, 1906.]

—BAKER, M. Geographic Dictionary of Alaska. [U. S. Geological Survey, Bulletin No. 299; Series F, Geography, 52. Washington, 1906.]

—BAKER, M. B. Clay and the Clay Industry of Ontario. [Report of the Bureau of Mines, 1906, Vol. XV, Part II. Toronto, 1906.]

—BALL, S. H. Pre-Cambrian Rocks of the Georgetown Quadrangle, Colorado. [From The American Journal of Science, Vol. XXI, May, 1906.]

—BARBOUR, E. H., and WARD, H. B. Preliminary Report on the Primitive Man of Nebraska. [Nebraska Geological Survey, Vol. II, Part V. Lincoln, 1906.]

—BARROWS, H. K., and HORTON, R. E. Determination of Stream Flow during the Frozen Season. [U. S. Geological Survey, Water-Supply and Irrigation, Paper No. 187; Series M, General Hydrographic Investigation, 19. Washington, 1907.]

—BARROWS, H. K., and HOYT, J. C. Report of Progress of Stream Measurements for the Calendar Year, 1905, Part I. Atlantic Coast of New England Drainage. [U. S. Geological Survey, Water-Supply and Irrigation, Paper No. 165; Series P, Hydrographic Progress Reports, 41. Washington, 1906.]

—BEEDE, J. W., and ROGERS, A. F. Coal Measures: Faunal Studies, IV. [The Kansas University Science Bulletin, Vol. III, No. 10, April, 1906.]

—BERKEY, C. P. Paleogeography of Saint Peter Time. [Bulletin of the Geological Society of America, Vol. XVII, pp. 229–50, Pl. 24. Rochester, June, 1906.]

—BEYER, S. W. Supplementary Report on Portland Cement Materials in Iowa. [Iowa Geological Survey, Bulletin No. 3. Des Moines, 1906.]

—BLATCHLEY, W. S. The Petroleum Industry of Southeastern Illinois. [Illinois State Geological Survey, Bulletin No. 2. Urbana, 1906.]

—BOWNOCKER, D.Sc., J. A. Salt Deposits and the Salt Industry in Ohio. [Geological Survey of Ohio, Fourth Series, Bulletin No. 8. Columbus, June, 1906.]

—BRANNER, J. C. A Bibliography of Clays and the Ceramic Arts. [The American Ceramic Society. Washington, 1906.]

—British Association for the Advancement of Science, Report of the Seventy-sixth Meeting of the. York, August, 1906. [London, 1907.]

—BRÖGGER, Prof. Dr. W. C. Die Mineralien der südnorwegischen Granit-pegmatitgänge. I. Niobate, Tantalate, Titanate und Titanoniobate. [Videnskabs-Selskabets Skrifter, Math.-Natur. Klasse, 1906, No. 6. Kristiania, 1906.]

———Hellandit von Lindvikskollen bei Kragerö, Norwegen. [Sonderabdruck aus: "Zeitschrift für Krystallographie u. s. w.," XLII. Band 5 Heft. Leipzig, 1906.]

—BROOKS, A. H. Railway Routes in Alaska. [Reprinted from the National Geographic Magazine, March, 1907. Washington, D. C., 1907.]

———The Geography and Geology of Alaska: A Summary of Existing Knowledge. With a Section on Climate by Cleveland Abbe, Jr., and a Topographic Map and Description Thereof by R. U. Goode. [U. S. Geological Survey, Professional Paper No. 45; Series B, Descriptive Geology, 75; Series F, Geography, 46. Washington, 1906.]

—BROWN, T. C. Columbia Field Work in 1905. Intercollegiate Field Courses in Geology. [Reprinted from Science, N. S., Vol. XXIII., No. 589, pp. 587–90, April 13, 1906.]

—BRUCE, F.R.S.E., WM. S. The Area of Unknown Antarctic Regions Compared with Australia, Unknown Arctic Regions, and British Isles. [Reprinted from the Scottish Geographical Magazine, July, 1906.]

—BUCKINGHAM, E. Studies on the Movement of Soil Moisture. [U. S. Department of Agriculture, Bureau of Soils—Bulletin No. 38. Washington, February 14, 1907.]

—BUCKLEY, E. R. Biennial Report of the State Geologist transmitted by the Board of Managers of the Board of Geology and Mines to the Forty-fourth General Assembly. [Missouri Bureau of Geology and Mines. Jefferson City, 1906.]

—BUCKLEY, E. R., and BUEHLER, H. A. The Geology of the Granby Area. [Missouri Bureau of Geology and Mines, Vol. IV, Second Series. Jefferson City, Mo.]

—CLARK, W. B. What Should Appear in the Report of a State Geologist. [Reprinted from Economic Geology, Vol. I, No. 5, March-April, 1906.]

—CLARKE, F. W. The Statistical Method in Chemical Geology. [Reprinted from Proceedings of the American Philosophical Society. Vol. XLV. 1906.

—Clays, Investigations Relating to, by the U. S. Geological Survey in 1905. [Extract from Bulletin No. 285; Contributions to Economic Geology, 1905. Washington, 1906.]

—COLEMAN, A. P. Interglacial Periods in Canada. [Imprenta y Fototipía de la Secretaría de Fomento. Mexico, 1906.]

—CONDON, T. A New Fossil Pinniped from the Miocene of the Oregon Coast. [University of Oregon Bulletin Supplement to Vol. III, No. 3, Department of Geology. Eugene, May, 1906.]

—COOKE, W. W. Distribution and Migration of North American Ducks, Geese, and Swans. [U. S. Department of Agriculture, Biological Survey—Bulletin No. 26. Washington, 1906.]

—CROOK, A. R. The Making of the Grand Cañon of the Colorado. [Reprinted from The Popular Science Monthly, November, 1906.]

—DALL, W. H. Biographical Memoir of Charles Emerson Beecher, 1856–1904. [Read before the National Academy of Sciences, November 16, 1904. Washington, 1907.]

—DALY, R. A. Abyssal Igneous Injection as a Causal Condition and as an Effect of Mountain-Building. [From The American Journal of Science, Vol. XXII, September, 1906.]

———The Differentiation of a Secondary Magma through Gravitative Adjustment. [Sonder-Abdruck aus der Festschrift zum siebzigsten Geburtstage von Harry Rosenbusch gewidm. v. seinen Schülern. Stuttgart, 1906.]

———The Limeless Ocean of Pre-Cambrian Time. [From The American Journal of Science, Vol. XXIII, February, 1907.]

———The Okanagan Composite Batholith of the Cascade Mountain System. [Bulletin of the Geological Society of America, Vol. XVII, pp. 329–76. Rochester, July, 1906.]

—DOWLING, D. B. Cretaceous Section in the Moose Mountains District, Southern Alberta. [Bulletin of the Geological Society of America, Vol. XVII, pp. 295–302. Rochester, June, 1906.]

—DARTON, N. H. Fish Remains in Ordovician Rocks in Bighorn Mountains, Wyoming, with a Résumé of the Northwest. [Bulletin of the Geological Society of America, Vol. XVII, pp. 541–66, Pls. 73–79. Rochester, 1906.]

———Geology of the Owl Creek Mountains, with Notes on Resources of Adjoining Regions in the Ceded Portion of the Shoshone Indian Reservation, Wyoming. [Fifty-ninth Congress, 1st Session, Senate, Document No. 219 Washington, February, 1906.]

—DAVIS, W. W. Biographical Memoir of George Perkins Marsh. [Read before the National Academy of Sciences, April 18, 1906. Washington, 1907.]

———Glacial Erosion in the Sawatch Range, Colorado. [Extract from Appalachia, Vol. X, No. 4.]

———Observations in South Africa. [Bulletin of the Geological Society of America, Vol. XVII, pp. 377–450, Pls. 47–54. Rochester, August, 1906.]

—DAVISON, C. The Doncaster Earthquake of April 23, 1905. [From the Quarterly Journal of the Geological Society, Vol. LXII, 1906, pp. 5–12 and Pl. 11—Map.]

—DAY, A. L., and SHEPERD, E. S., The Lime-Silica Series of Minerals, with Optical Study by Fred E. Wright. [From The American Journal of Science, Vol. XXII, October, 1906.]

—DAY, D. T. Mineral Products of the United States, Calendar Years 1896 to 1905. [Department of the Interior, U. S. Geological Survey. Washington, 1906.]

———Mineral Resources of the United States, Calendar Year 1905. [U. S. Geological Survey. Washington, 1906.]

—DRESSER, J. A. A Study in the Metamorphic Rocks of the St. Francis Valley, Quebec. [From The American Journal of Science, Vol. XXI, January, 1906.]

———Igneous Rocks of the Eastern Townships of Quebec. [Bulletin of the Geological Society of America, Vol. XVII, pp. 497–522, Pls. 67–68. Rochester, October, 1906.]

—EASTMAN, C. R. Dipnoan Affinities of Arthrodires. [From The American Journal of Science, Vol. XXI, February, 1906.]

—Economic Geology, Contributions to, 1905. [U. S. Geological Survey, Bulletin No. 285. Series A, Economic Geology, 73. Washington, 1906.]

—EIGENMANN, C. H. On a Collection of Fishes from Buenos Aires. [Proceedings of the Washington Academy of Sciences, Vol. VIII, pp. 449–58, Pls. XXI–XXIII. Washington, March 4, 1907.]

—ELLIOT, Sc.D., F.R.S.E., etc., D. G. A Catalogue of the Collection of Mammals in the Field Columbian Museum. [Field Columbian Museum, Publication No. 115; Zoölogical Series, Vol. VIII. Chicago, 1907.]

—ELLIS, R. W. The Roads and Road Materials of Southeastern Indiana. [From the Thirtieth Annual Report of the Department of Geology and Natural Resources of Indiana, 1905. Indianapolis, 1906.]

—EMMONS, S. F. Biographical Memoir of Clarence King, 1842–1901. [Read before the National Academy of Sciences April 23, 1903. Washington, 1907.]

—Travaux de la section géologique du cabinet de Sa Majesté. Vol. VI. Livr. 2, et derniere.

—ETHERIDGE, JUNR. J. P. R., and DUN, W. S. A Monograph of the Carboniferous and Permo-Carboniferous Invertebrata of New South Wales. Vol. II.—Pelecypoda. Part I.—The Pelæopectens. [Department of Mines and Agriculture, Memoirs of the Geological Survey of New South Wales; Palæontology, No. 5. Sydney, 1906.]

—FAIRCHILD, H. L. Proceedings of the Seventeenth Annual Meeting, held at Philadelphia, Pennsylvania, December 29, 30, and 31, 1904, including Proceedings of the Sixth Annual Meeting of the Cordilleran Section, held at Berkeley, California, December 30 and 31, 1904. [Bulletin of the Geological Society of America, Vol. XVI, pp. 531–636, Pls. 90–94. Rochester, April, 1906.]

—FARRINGTON, PH.D., O. C. The Shelburne and South Bend Meteorites. [Field Columbian Museum, Publication 109, Geological Series, Vol. III, No. 2. Chicago, February 1, 1906.]

———Zoisite from Lower California. [Field Columbian Museum, Publication 112; Geological Series, Vol. III, No. 4. Chicago, May 15, 1906.]

—FISHER, E. F. Terraces of the West River, Brattleboro, Vermont. [Proceedings of the Boston Society of Natural History, Vol. XXXIII, No. 2, pp. 9–24, Pls. 1–11. Boston, October, 1906.]

—FISHER, W. K. New Starfishes from the Pacific Coast of North America. [Proceedings of the Washington Academy of Sciences, Vol. VIII, pp. 111–39. August 14, 1906.]

—FULLER, M. L. The Production of Carbon Dioxide. [Extract from Mineral Resources of the United States, Calendar Year 1905, U. S. Geological Survey, Washington, 1906.]

———The Production of Mineral Waters in 1905. [Extract from Mineral Resources of the United States, U. S. Geological Survey. Washington, 1906.]

—GAGEL, C. Aufnahmeergebnisse in Lauenburg. Bericht über die Aufnahme der Blätter Gudow, Seedorf, Zarrentin, Nusse und Siebeneichen im Jahre 1904. [Sonderabdruck aus dem Jahrbuch der königl. preuss. geologischen Landesanstalt und Bergakademie für 1904. Band XXV, Heft 4. Berlin, 1906.]

—GANNETT, H. Manual of Topographic Methods. [U. S. Geological Survey, Bulletin No. 307, Series F, Geography, 56. Washington, 1906.]

———Results of Primary Triangulation and Primary Traverse. Fiscal Year 1905–6. [U. S. Geological Survey, Bulletin No. 310; Series F, Geography, 57. Washington, 1907.]

—GANNETT, H. The Areas of the United States, the States, and the Territories. [U. S. Geological Survey, Bulletin No. 302; Series F, Geography, 53. Washington, 1906.]

—GARDNER, F. D. The Wire-Basket Method for Determining the Manurial Requirements of Soils. [U. S. Department of Agriculture, Bureau of Soils, Circular No. 18.]

—Geological Literature Added to the Geological Society's Library during the Year Ended December 31, 1905. [Geological Society, London, 1906.]

—Geological Society of London, List of the. [November 15, 1906.]

—GIBBS, J. W. Art. XLIV.—Certain Suggestions on Geophysical Research. [From The American Journal of Science, Vol. XXI, June, 1906.]

—GIDLEY, J. W. Evidence Bearing on Tooth-Cusp Development. [Proceedings of the Washington Academy of Sciences, Vol. VIII, pp. 91–110. Washington, July 10, 1906.]

—GILBERT, G. K. The Investigation of the San Francisco Earthquake. [Reprinted from The Popular Science Monthly, August, 1906.]

———Rate of Recession of Niagara Falls. Accompanied by a Report on the Survey of the Crest, by W. Carvel Hall. [U. S. Geological Survey, Bulletin 306; Series B, Descriptive Geology, 109; Series F, Geography, 54. Washington, 1907.]

—GLANGEAUD, M. PH. Les Volcans du Livradois et de la Comté (Puy-de-Dôme). [Gauthier-Villars, Imprimeur-Libraire des Comptes Rendus des séances de l'Academie des Sciences. Paris, 12 mars 1906.]

———Reconstitution d'un ancien lac oligocène sur le versant nord du Massif du Mont-Dore (lac d'Olby). [Gauthier-Villars, Imprimeur-Libraire des Comptes Rendus des séances de l'Academie des Sciences. Paris, 22 janvier 1906.]

———Une ancienne chaîne volcanique au nord-ouest de la chaîne des Pays. [Gauthier-Villars, Imprimeur-Libraire des Comptes Rendus des séances de l'Academie des Sciences. Paris, 15 janvier 1906.]

———Une Chaîne Volcanizée Miocène sur le bord occidental de la Limagne. [Gauthier-Villars Imprimeur-Libraire des Comptes Rendus des séances de l'Academie des Sciences. Paris, 5 mars 1906.]

—GORDON, C. E. Studies on Early Stages in Paleozoic Corals. [From The American Journal of Science, Vol. XXI, February, 1906.]

—GORDON, C. H., and GRATON, L. C. Lower Paleozoic Formations in New Mexico. [From The American Journal of Science, Vol. XXI, May, 1906.]

—GRABAU, A. W. Types of Sedimentary Overlap. [Bulletin of the Geological Society of America, Vol. XVII, pp. 567–636. Rochester, December, 1906.)

—GRANT, U. S. Copper and Other Mineral Resources of Prince William Sound, Alaska. [From U. S. Geological Survey, Bulletin No. 284, pp. 78–87, 1906.]

—GREGORY, PH.D., H. E., and ROBINSON, C.E., PH.D., H. H. Preliminary

Geological Map of Connecticut. [State of Connecticut State Geological and Natural History Survey, Bulletin No. 7. Hartford, 1907.]

—HALE, G. E., and ADAMS, WALTER S. Sun-Spot Lines in the Spectra of Red Stars. Contributions from the Solar Observatory, Mt. Wilson, California. No. 8. [Reprinted from the Astrophysical Journal, Vol. XXIII, pp. 400–5, June, 1906.]

—HALL, A. Biographical Memoir of John Rodgers, 1812–82. [Read before the National Academy of Sciences, April 18, 1906. Washington, 1907.]

—HALL, M. R., HANNA, F. W., and HOYT, J. C. Report of Progress of Stream Measurements for the Calendar Year 1905. Part V.—Ohio and Lower Eastern Mississippi River Drainages. [U. S. Geological Survey, Water-Supply and Irrigation, Paper No. 169; Series P, Hydrographic Progress Reports, 45. Washington, 1906.]

—HALL, M. R., and HOYT, J. C. Report of Progress of Stream Measurements for the Calendar Year 1905. Part IV.—Santee, Savannah, Ogeechee, and Altamaha Rivers and Eastern Gulf of Mexico Drainages. [U. S. Geological Survey, Water-Supply and Irrigation, Paper No. 168; Series P, Hydrographic Progress Reports, 44. Washington, 1906.]

—HANNA, F. W., and HOYT, J. C. Report of Progress of Stream Measurements for the Calendar Year 1905. Part VII.—Hudson Bay and Upper Eastern and Western Mississippi River Drainages. [U. S. Geological Survey, Water-Supply and Irrigation Paper, No. 171; Series P, Hydrographic Progress Reports, 47. Washington, 1906.]

—HARRISON, C.M.G., M.A.F.I.C., F.G.S., J. B. Explanation of the Geological Map of Parts of the Essequibo and Cuyuni Rivers. [Georgetown Demerera, British Guiana. 1906.]

—HART, C. A., and GLEASON, PH.D., H. A. On the Biology of the Sand Areas of Illinois. [Bulletin of the Illinois State Laboratory of Natural History, Urbana; Vol. VII, Article VII. January, 1907.]

—HARTNAGEL, C. A. Stratigraphic Relations of the Oneida Conglomerate. Also Upper Siluric and Lower Devonic Formations of the Skunnemunk Mountain Region. [From N. Y. State Museum Bulletin 107, Miscellaneous Papers. Albany, December 17, 1906.]

—HASTINGS, J. B., and BERKEY, C. P. The Geology and Petrography of the Goldfield Mining District, Nevada. [Transactions of the American Institute of Mining Engineers. Bethlehem Meeting, February, 1906.]

—HATCH, F. H. Presidential Address, Delivered to the Geological Society of South Africa, at the Annual Meeting, on the 29th of January, 1906. [From The Proceedings of the Geological Society of S. Africa, 1906, pp. xxi–xxxiv.]

—HAYFORD, C.E., J. F. The Geodetic Evidence of Isostasy, with a Consideration of the Depth and Completeness of the Isostatic Compensation and of the Bearing of the Evidence upon Some of the Greater Problems of Geology. [Proceedings of the Washington Academy of Sciences, Vol. VIII, pp. 25–40. Washington, May 18, 1906.]

—HERRE, A.M., A. W. C. T. The Foliaceous and Fruticose Lichens of the Santa Cruz Peninsula, California. [Proceedings of the Washington Academy of Sciences, Vol. VII, pp. 325–96. Washington, March 29, 1906.]

—HILL, R. N. J. B. The Older and Newer Palaeozoics of West Cornwall. [Extracted from the Geological Magazine, N. S., Decade V, Vol. III, May, 1906, pp. 206–16. London.]

—HITCHCOOK, LL.D., C. H. Geology of Diamond Head, Oahu. Mohokea Caldera. [Bulletin of the Geological Society of America, Vol. XVII, pp. 469–96, Pls. 59–66. Rochester, October, 1906.]

—HITCHCOCK, LL.D., C. H. The Champlain Deposits of Northern Vermont. [From the Fifth Report on the Geology of Vermont by Professor G. H. Perkins. Montpelier, 1906.]

———The Bible and Recent Science. [Reprinted from the Bibliotheca Sacra, April, 1907.]

—HIXON, H. W. Magmatic Waters. [Journal Canadian Mining Institute, Part of Vol. X. Toronto Meeting, March, 1907.]

———The Ore Deposits and Geology of the Sudbury District. [Journal Canadian Institute, Part of Vol. IX. Quebec Meeting, 1906.]

———The Smelting of Cobalt Ores. [Journal of the Canadian Mining Institute, Part of Vol. X. Toronto Meeting, 1907.]

—HIBBS, W. H. America and Seismological Research. [Reprinted from The
O Popular Science Monthly, September, 1906.]

———Guadix Formation of Granada, Spain. [Bulletin of the Geological Society of America, Vol. XVII, pp. 285–94, Pls. 35–36. Rochester, June, 1906.]

—HOLLICK, A. The Cretaceous Flora of Southern New York and New England. [Monographs of the U. S. Geological Survey, Vol. L. Washington, 1906.]

—HORTON, R. E., GROVER, N. C., and HOYT, J. C. Report of Progress of Stream Measurements for the Calendar Year 1905. Part II.—Hudson, Passaic, Raritan, and Delaware River Drainages. [U. S. Geological Survey, Water-Supply and Irrigation, Paper No. 166; Series P, Hydrographic Progress Reports, 42. Washington, 1906.]

—HUSTON, S. First Annual Report of the State of Ohio Highway Department, February 15, 1905, to November 15, 1905. [Columbus, April, 1906.]

—Iowa Geological Survey. Annual Report, 1905, with Accompanying Papers. [Vol. XVI. Des Moines, 1906.]

—JACK, LL.D., F.G.S., F.R.G.S., R. L. The Prospects of Obtaining Artesian Water in the Kimberley District. [Western Australia, Geological Survey, Bulletin No. 25. Perth, 1906.]

—JULIEN, A. A. The Occlusion of Igneous Rock within Metamorphic Schists, as Illustrated on and near Manhattan Island, New York. [Reprinted from the Annals N. Y. Academy of Sciences, Vol. XVI, Part III, March, 1906.]

THE

JOURNAL OF GEOLOGY

SEPTEMBER–OCTOBER, 1907

THE PRE-RICHMOND UNCONFORMITY IN THE MISSISSIPPI VALLEY

STUART WELLER

Ulrich and Schuchert[1] have called attention to the widespread emergence of the land in the interior of North America at the beginning of the Richmond stage of later Ordovician time, and the resubmergence of the same during the later portion of the same stage. This epoch in the geologic history of the North American continent is one which has usually been overlooked, but which, nevertheless, is of vast importance.

During mid-Ordovician time a great interior sea reached westward from Appalachia to the Rocky Mountain region. In this sea the Trenton limestone of New York, New Jersey, and Pennsylvania was being deposited, as well as the equivalents of this formation farther west, the Galena limestone of Wisconsin, Minnesota, northern Illinois, and Iowa, and the Kimmswick limestone of southern Illinois and southern Missouri. In the Big Horn Mountains of Wyoming the greater portion of the Big Horn limestone is also contemporaneous in age with the Trenton and Kimmswick limestones of the east. In the regions between these outcropping areas, now occupied by younger formations, limestones of similar age are doubtless buried beneath the younger strata.

Following mid-Ordovician or Mohawkian time, this great interior sea became much contracted, so that the beds of Utica and Lorraine

[1] E. O. Ulrich and Charles Schuchert, "Paleozoic Seas and Barriers in Eastern North America," *Report of the New York Paleontologist for 1901*, pp. 645, 646.

age, the two lower divisions of the upper Ordovician or Cincinnatian period, are restricted, so far as known, chiefly to the region lying east of the Cincinnati arch. During Richmond time, however, the interior sea again transgressed to the west and north until it again stretched from Appalachia to the Rocky Mountain region. The evidence for this withdrawal and readvance of the interior sea in post-Trenton times is both paleontologic and stratigraphic in nature, and some portions of this evidence will be considered in the following pages.

In the earlier work of the geologists of Illinois, Wisconsin, Iowa, and Missouri, no important subdivisions of the Cincinnatian, or "Hudson River" as it was usually termed, were recognized, and consequently, in the absence of any conspicuous stratigraphic unconformity, the sequence from the Trenton limestone or its equivalent to the close of the Ordovician seemed to be complete. More recent critical investigation of the Cincinnatian faunas in the Ohio Valley has demonstrated that at least three distinct faunal divisions, the Utica, Lorraine, and Richmond, are included in the period, and the only one of these which has been recognized anywhere in Illinois and Wisconsin or in the region to the west belongs to the highest or Richmond division of the Cincinnatian period.

The fauna of the Richmond in the Mississippi Valley exhibits two facies, or perhaps more properly two sub-stages, which are more or less different in character. In the Richmond fauna proper, as typified by the fauna of the beds at Richmond Indiana, the brachiopod *Rhynchotrema capax* is by far the most characteristic species, and beds bearing this same fauna occur at many localities in Illinois, Wisconsin, and Missouri.

In northwestern Illinois and eastern Iowa, however, a second faunal facies occurs in the Maquoketa shales, where an important element in the fauna consists of a large number of small pelecypod shells belonging to the genera *Cleidophorus* and *Ctenodonta*, *Cleidophorus neglectus* being perhaps the most conspicuous species. The fauna of the Maquoketa beds, however, is not uniform throughout, and faunules are frequently present in Iowa and elsewhere containing examples of *Rhynchotrema capax* and other members of the typical Richmond fauna. At points farther south in the Mississippi Valley, in Jefferson County, Missouri, and Monroe County, Illinois,

the typical Maquoketa fauna with an abundance of *Cleidophorus neglectus* occurs in certain shales immediately superjacent to a limestone bearing the typical *Rhynchotrema capax* fauna of the Richmond, so that the Maquoketa is shown to be at least as young or even younger than the Richmond proper.

The faunal break in passing from the subjacent Trenton horizon to the superjacent Richmond or Maquoketa is sharp, there being little or nothing in common between the lower and the upper faunas, and the unconformity suggested by this faunal change is confirmed by an actual physical unconformity between the strata over a large area.

The locality where the physical unconformity is most conspicuously shown is in southern Calhoun County, Illinois, on Madison Creek south of Batchtown. At this point the typical Richmond with its *Rhynchotrema capax* fauna does not occur, the section being as follows:

1. *Maquoketa shale*, 75 feet in thickness. In the upper part this formation is a very fine-grained clay shale of a light greenish color, weathering to an olive green, some layers containing an abundance of graptolites. In its lower beds the formation becomes yellower in color and more gritty in texture, and in the lowest six or eight feet are several harder and still more gritty beds from one to three inches in thickness which stand out upon weathered banks by reason of their greater resistance. In these harder layers fossils rarely occur, the only two genera observed being *Leptobolus* and *Cleidophorus*. At the very base of the formation is a granular bed one inch or less in thickness which is filled with examples of *Cleidophorus neglectus*, besides several species of *Ctenodonta*, a small *Orthoceras*, several gastropod shells, and an occasional fragment of a trilobite.

2. *Red residuary clay*, four to ten inches in thickness, in which are imbedded numerous angular, fossiliferous cherts.

3. *Kimmswick limestone*, ± 50 feet in thickness. This is a light-colored, highly fossiliferous, crystalline limestone of Trenton age. Its superior surface is very uneven beneath the residuary red clay that rests upon it.

The unconformity in this section is represented by the red residuary clay lying between the Kimmswick limestone and the Maquo-

keta formation. This material can only have been formed as the product of the subaerial decay of rocks, doubtless of limestones which originally were present above the present uppermost layer of the Kimmswick limestone. The deposit is similar in every respect to the red residuary clays which are so uniformly present in southern Missouri and elsewhere beyond the glacial border, sometimes many feet in thickness, and containing the resistant cherts which were originally included in the limestone formations now destroyed by

FIG 1.—Unconformity between Kimmswick limestone and Maquoketa shale near Batchtown, Calhoun Co., Ill. A, Kimmswick limestone; B, Red residuary clay; C, Maquoketa shale.

weathering. The presence of this residuary clay in the section is conclusive evidence of the existence of an area of dry land in the Mississippi Valley region, probably of long duration, between the period of deposition of the subjacent Kimmswick limestone and the superjacent Maquoketa shale. The presence of this bed at this point is perhaps only local, but the remarkable fact is that any of this residuary clay should have been preserved actually *in situ*. With the readvance of the sea it would seem that the wave action would have washed the underlying hard rocks clean of their covering, and indeed the few inches here present may be only the remnant of a former

much thicker bed. That these few inches of clay, however, are in the main actually undisturbed is quite apparent, only the uppermost layer, a fraction of an inch in thickness, showing evidence of having been reworked by the waves; by reason of the mingling of Maquoketa fossils.

In passing southward this stratigraphic interval is next encountered in St. Louis and Jefferson Counties, Missouri, and in Monroe County, Illinois. In none of this more southern area has such a striking instance of physical unconformity been observed as that near Batchtown, but the unconformity is none the less distinctly shown. The section in this region is slightly different from the Calhoun County section, by reason of the presence of the true Richmond with its *Rhynchotrema capax* fauna, and may be somewhat generalized as follows:

1. *Burlington limestone* and *Kinderhook beds*, whose differentiation is not of importance in this place, resting unconformably upon the Maquoketa shale.

2. *Maquoketa shale*, 4 to 30 feet in thickness, often with abundant graptolites in the higher beds, and with the typical *Cleidophorus neglectus* fauna at the base. This formation exhibits much variation in different vertical sections in the region, but it always contains the typical Maquoketa fauna.

3. *Richmond limestone*, ± 2 feet in thickness. This is a hard, more or less impure limestone, somewhat darker colored than that below. It is abundantly fossiliferous, the most conspicuous species being *Rhynchotrema capax*. This bed is remarkably uniform in character, both lithologically and faunally, throughout this region of outcrop.

4. *Kimmswick limestone*, ± 50 feet in thickness. The outcrop of this limestone along the Mississippi River in Jefferson County constitutes the typical expression of the formation. It is remarkably uniform in all of its characters, with the same formation in Calhoun County.

In any single vertical section in this region the physical unconformity between the Kimmswick limestone and the Richmond bed is not conspicuously exhibited, although the faunal change is sudden and complete. In following the contact from the section at the railroad cut one mile south of Kimmswick, however, to the quarry at Glen Park, and then in the sections of the river bluffs to an aban-

doned quarry one-half mile farther down stream, a total distance of from two and one half to three miles, it is clearly seen that the Richmond rests upon higher and higher strata of the Kimmswick limestone. At the northern end of this section the uppermost bed of the Kimmswick, immediately beneath the Richmond, is characterized by a fauna in which bryozoans are the most conspicuous element. At Glen Park the upper bed of the Kimmswick is a higher stratum than that farther north, and the fauna contains more trilobites and pelecypods. Farther south a still higher bed of the Kimmswick limestone, characterized by many specimens of a large *Receptaculites*, is immediately subjacent to the Richmond. These stratigraphic conditions clearly indicate that in post-Kimmswick time the region was elevated above sea level, and the beds obliquely truncated before the deposition of the Richmond. The time hiatus represented by the unconformity in this region, as in Calhoun County, is doubtless the period during which the Utica and Lorraine formations were being deposited east of the Cincinnati arch.

In Monroe County, Illinois, conditions identical with those in Jefferson County, Missouri, are shown in the quarry of the St. L. I. M. & S. R. R. at Valmeyer. Still farther south, at Cape Girardeau, Missouri, the same section is repeated in the same manner, although the details have not been so carefully studied as in the more northern localities.

In the northern portion of the Mississippi Valley region, in eastern Iowa, northwestern Illinois, and Wisconsin, no stratigraphic break between the Galena limestone below, which is contemporaneous with the Kimmswick limestone, and the superjacent Maquoketa shales has been certainly established, but the faunal break is essentially identical with that in Calhoun County where the physical break is clearly shown, and one is forced to the conclusion that the physical unconformity is really present, although obscured.

Westward from the Mississippi River, across the great plains, the older rocks are completely buried beneath younger formations. In the Big Horn Mountains in Wyoming, however, as has recently been shown by Darton,[1] conditions are present which are comparable to

[1] "Geology of the Big-Horn Mountains," *U. S. Geological Survey*, P. R. No. 51, pp. 26–29; also *Bull. Geol. Soc. Am.*, Vol. XVII, p. 547.

those in the Mississippi Valley. In this western region the great mass of the Big Horn limestone corresponds essentially in age to the Kimmswick limestone, but at the summit of the formation, in discontinuous, pocket-like areas, as if deposited unconformably upon the eroded or weathered surface of the subjacent beds, are strata bearing a rich and typical Richmond fauna with *Rhynchotrema capax*.

With this unconformity clearly established in the Mississippi Valley and in the Big Horn Mountains, and with the faunal conditions so nearly alike in the two regions, we seem to be justified in considering the same unconformity as being present in all the intervening area. If this conclusion is well founded, there must have been in post-Trenton time a great expanse of dry land in the interior of the North American continent, reaching from the Cincinnati arch probably to the Rocky Mountain region, which in Richmond time was resubmerged.

Such a widespread emergence and resubmergence of the interior of the continent should constitute an important and clearly marked epoch in geologic history, perhaps of sufficient importance to rank as a major division in this history. As we now understand the facts, there seems to be no such conspicuous break between the recognized summit of the Ordovician and the base of the Silurian, as this preceding the Richmond. A thorough and systematic investigation of the entire Richmond and Maquoketa fauna, together with a careful comparison with the earliest Silurian faunas is highly desirable. It is especially desirable that the earliest faunas of the Medina sandstone of the east be better known, in order to determine whether there exists any relationship between them and the Richmond faunas of the Mississippi Valley. In a certain way the Richmond is perhaps analogous with the Helderbergian which was formerly considered as the youngest Silurian, but is now almost universally considered as the oldest Devonian. It is certainly within the limits of possibility that, with a more complete knowledge of the facts, the Richmond may be transferred in a similar way, and be considered as the oldest Silurian, rather than as the youngest Ordovician.

ON THE ORIGIN AND DEFINITION OF THE GEOLOGIC TERM "LARAMIE"[1]

A. C. VEATCH

TABLE OF CONTENTS

INTRODUCTION

Investigations of the United States Geological Survey during the summer of 1906, covering the larger part of the Laramie exposures on the Laramie Plains, examined by the King and Hayden surveys, have revealed many new and important facts bearing on the Laramie problem.

By detailed areal surveys it was found: (1) that the lignitiferous series, which in the Laramie Plains lies between the Montana below and the Fort Union above, and has a maximum thickness of about 12,500 feet, is divided about the middle by an unconformity; (2) that this unconformity is in the same stratigraphic plane and continuous with the unconformity which in the vicinity of Carbon and to the southeast separates all the Laramie beds studied by the Hayden and King parties from the underlying Cretaceous; (3) that the beds above the unconformity rest, often with great divergence of dip, on all the underlying beds down to and including the Dakota; (4) that the basal conglomerate, locally well developed at the horizon of the unconformity, while composed largely of materials derived from the underlying Cretaceous rocks, notably the Benton, contains pebbles and bowlders from the pre-Cambrian crystallines now exposed in

[1] Published by permission of Director of the U. S. Geological Survey.

the hearts of the surrounding ranges. This unconformity thus involves the total thickness of the Cretaceous portion of the beds below the unconformity, and probably the whole sedimentary series of this region, or over 20,000 feet of strata.

The Laramie Plains section in brief is as follows:

GENERALIZED SECTION OF THE ROCKS OF THE WESTERN PART OF THE LARAMIE PLAINS IN CARBON COUNTY, WYOMING

	North Park Tertiary		4,500+
	Unconformity		
	Fort Union		800–2,000
	"Upper Laramie"		6,000
	Unconformity		
	"Lower Laramie"		6,500
Montana	Lewis	"Fox Hills" of the early surveys	3,000
	Mesa Verde		3,200
	"Pierre shale"[1]		3,500
Colorado	Niobrara		800
	Benton		1,500
	Dakota		150
	Morrison		200
	Marine Jurassic		75
	Red beds		1,650
	Carboniferous sandstone and limestone with basal conglomeratic quartzite		1,800
	Pre-Cambrian crystallines		

It may be said that in the areas examined by the Hayden and King parties, all of which were immediately along and south of the Union Pacific Railroad, the lower division is usually absent, the upper resting generally on one or another of the members of the Montana, but at one point extending over on to the Dakota. The large development of the division beneath the unconformity and above the Montana, corresponding to the "Lower Laramie" of literature, lies entirely north of the area they studied, and its existence was not known until the work of the past season.

[1] It is the belief of Dr. T. W. Stanton that the Mesa Verde and part of the Lewis belong to the Pierre, as that formation is developed east of the Rocky Mountains. A local name will therefore be applied to this lowest division of the Montana in this section.

PRESENT USAGE OF THE TERM "LARAMIE"

The three principal usages of the term "Laramie" today are shown in the recent textbook of geology by Chamberlin and Salisbury. Here "Laramie series" is applied to all the beds between the Montana and Fort Union. Upper Laramie and Lower Laramie or "Laramie proper" are applied respectively to the beds above and below the great unconformity, first shown by Cross to exist in the Denver region, then found by Weed in western Montana, in 1905 found in southern Uinta County, Wyoming, by the writer, and traced northward by Dr. Schultz in 1906 to a point just south of Yellowstone National Park, and again found in 1906, most strikingly developed, in Carbon County, Wyoming, in the western part of the Laramie Plains. The Lower Laramie has also been called "true Laramie," and sometimes simply Laramie. The complexness of the situation is excellently illustrated by the use of "Laramie" by Stanton and Knowlton in seven different combinations on a single page of their report, namely "Laramie series," "true Laramie," "so-called Laramie," "original Laramie," "typical Laramie," "the Laramie," "supposed true Laramie."[1]

Because of the frequent and necessary reference to the upper and lower divisions in the present discussion, the names "Upper Laramie" and "Lower Laramie" will be applied in this discussion in the sense used by Chamberlin and Salisbury, and in other geologic literature.

KING'S STATEMENT

A critical historical consideration of the origin of the word "Laramie," which may be expected to lead to some scientifically defensible conclusion regarding what the term can and cannot be properly used for, may very naturally begin with King's explanation in his *Systematic Geology of the Exploration of the Fortieth Parallel.* King here makes three important references to the subject, which because of their intimate bearing on this discussion are quoted at length:

Conformably overlying the Fox Hill group of Hayden is a considerable series of rocks over which a conflict of opinion now exists. These rocks Dr. Hayden has successively considered as Tertiary and as transitional between the Cretaceous

[1] "Stratigraphy and Paleontology of the Laramie and Later Formations in Wyoming," *Bulletin of the Geological Society of America*, Vol. VIII (1897), p. 128.

and the Tertiary. They conformably overlie the Fox Hill of Meek and Hayden, and are developed throughout a large part of Wyoming, as well as upon the great plains east of the Rocky Mountains south of the forty-first parallel. That there might be no misunderstanding as to the stratigraphical position and nature of the rocks themselves, Dr. Hayden and I mutually agreed to know them hereafter as the Laramie group, and to leave their age for the present as debatable ground, each referring them to the horizon which the evidence seemed to him to warrant.[1] . . . .

The great sandstone series of the Fox Hill is conformably overlain by a continuation of the sandstones, which attain a thickness of from 1,500 to 5,000 feet, varied very greatly in lithological character over different areas, but in general characterized by the frequent occurrence of workable beds of lignite and innumerable seams of carbonaceous clay. The fossil forms which are found in this series have led to a disagreement, which has now become historic, as to the age of the beds. They were at first, by Meek and Hayden, held to be distinctly Tertiary. That opinion has since been so modified as to lead those gentlemen to designate them as beds of transition. On the other hand, Dr. Le Conte, Professor Newberry, Professor Stevenson, and Major Powell have all committed themselves to the view advanced by me in Volume III of this series in 1870, that the whole of the conformable series is Cretaceous. During the slow gathering of the evidence which shall finally turn the scale, I proposed to Dr. Hayden that we adopt a common name for the group, and that each should refer it to whatever age his data directed. Accordingly, as mentioned in the opening of this chapter, it was amicably agreed between us that this series should receive the group name of Laramie, and that it should be held to include that series of beds which conformably overlies the Fox Hill.[2] . . . .

Here, with those who follow Hayden, the Cretaceous series comes to an end. Conformably over this lies the group which Hayden and I have agreed to call the Laramie, which is his Lignitic group, and is considered by him as a transition member between Cretaceous and Tertiary. There is no difference between us as to the conformity of the Laramie group with the underlying Fox Hill. It is simply a question of determination of age upon which we differ.[3]

It is evident from the above: (1) that Laramie was adopted as a name for the beds which Hayden called Lignitic in Wyoming and Colorado,[4] and (2) that the beds so included were believed by both Hayden and King conformably to overlie the Fox Hills sandstone. Considered with other available data, it is unquestionably true that

[1] *Report of the Geological Exploration of the Fortieth Parallel*, Vol. I (1878), p. 298.

[2] *Ibid.*, p. 331.

[3] *Ibid.*, p. 348.

[4] This is further shown by the following phrases on p. 333 of King's report: "The Laramie or Lignitic period," "Hayden's Lignitic (now the Laramie) series."

both King and Hayden intended that the term should apply to the beds which occur between the Fox Hills and the Wasatch.

The consideration that the name was adopted as a substitute for Hayden's Lignitic suggests that the proper way to approach this somewhat involved subject is through the writings of Hayden. A number of collateral facts tend to strengthen the view that in a critical discussion of the origin and definition of Laramie the writings of Hayden are of prime importance. In the first place, King did not personally desire to investigate the region from Fort Bridger eastward, and only undertook it when the chief of engineers so directed. On January 23, 1871, he wrote the chief of engineers as follows:

> The parties under the charge of Dr. F. V. Hayden, geologist of the Interior Department, and that led by Professor O. C. Marsh, of Yale College, have devoted the past summer to the geological explorations of those portions of Wyoming and Colorado which I had intended to cover next summer. . . . . I am convinced that what I could do would add but little to results they have obtained. We should without doubt fill up minor gaps in the structural relations of the plains, but on the whole it seems to me that there is not sufficient inducement to warrant our devoting our time and funds to a field from which the cream has already been taken.

In a letter to the chief of engineers, dated February 9, 1871, he gave the exact limit of his previous work as follows:

> In answer to the communication of Colonel J. B. Wheeler which I have just received, concerning the extent of the Green River included within my explorations, I have the honor to say that no part of that section is embraced in the work already done. Our eastern limit is 30 miles west of the river. If my present plans are carried out, I had not intended to continue that way.

On the direction of the chief of engineers the work was continued eastward, but King's personal efforts were almost wholly devoted to the territory to the west of Green River. In 1871 S. F. Emmons passed rapidly up Bitter Creek Valley, examining the country as far east as Washakie. In 1872 he spent ten days, June 20 to 30, examining the immense territory west of the North Platte River, south of the Seminoe Mountains, and north of the Elk Mountains.[1] The outcrops in the Laramie Plains were examined by Arnold Hague in the fall of 1872. When King therefore agreed with Hayden on a

[1] King's manuscript letters to the chief of engineers, dated July 3, 1872, and February 17, 1873.

name which should be a substitute for and equivalent of Hayden's Lignitic as used in Colorado and Wyoming, he necessarily relied upon Hayden's work on the Laramie Plains with the corroboration furnished by the work of Hague and such hasty examinations as he may have made personally when visiting Hague's party. It is therefore essential to take up first the work of Hayden, and to trace the natural growth and development of his knowledge which made "Laramie" an entirely natural and desirable term to Hayden.

BOUNDARIES OF THE LARAMIE PLAINS

Before following up the suggested clue afforded by the writings of Hayden, it may be well to outline the boundaries of the Laramie Plains as they were understood at the time of the adoption of the word "Laramie." On all the army maps[1] of this region the Laramie Plains are shown as extending from the Front Range westward to the region of the North Platte River. In 1871 Professor Cyrus Thomas, of the Hayden Survey, gave the following definition of the Laramie Plains:[2]

> This section is bounded on the east and northeast by the Black Hills,[3] on the west by the West Rattlesnake Hills,[4] and on the southwest by Medicine Bow Mountains. It is somewhat quadrangular in shape, its average length from southeast to northwest being about 90 miles, and average width from northeast to southwest about 75 miles, containing (exclusive of the surrounding mountains) a surface area of about 6,750 square miles, or nearly 4,500,000 acres. It is drained chiefly by the Medicine Bow and Laramie Rivers and their tributaries, both affluents of the North Platte, which also traverses the extreme western border. The Laramie, rising in the mountains at the southwest angle, flows along the eastern border to the northeast angle of the section, where it breaks through the Black Hills and joins the North Platte in the plains beyond. The Medicine Bow, receiving affluents from each side, but principally from the south, flows through the western part of the section and joins the North Platte on the western border; which latter stream makes its exit at the northwest angle. . . . .
>
> The southeast part, to which the name "Laramie Plains" is sometimes limited, is decidedly the best portion of the section, and contains much the largest propor-

[1] These were the general maps in common use by the Hayden and King parties.

[2] *Fourth Annual Preliminary Report*, U. S. Geological Survey of Wyoming (being a *Second Annual Report of Progress*), (1871), pp. 220, 221.

[3] Now called the Laramie Hills or Front Range.

[4] Now called the "Haystacks" and situated just west of the North Platte River in Carbon County, Wyo.

tion of arable land. Counting from the head of the Laramie Valley to Rock Creek, it is about 70 miles long, with an average width of about 25 miles, giving an area of 1,750 square miles.

Thus there appear to have been two usages for the term "Laramie Plains"—one in common use on the army maps and, to a greater or less extent, among the people, as is shown in official reports of the surveyor general of Wyoming;[1] and a second restricted to the portion east of Rock River (sometimes also given as Medicine Bow River). The term was not extended to the plains west of the natural western limit afforded by the West Rattlesnake Hills or Haystacks. Hayden used the term in both senses. In his report for 1868 he says: "In the Laramie Plains, along the line of the Union Pacific Railroad, extensive beds of coal have been opened, and the coal is used for generating steam and for fuel on the cars."[2] This is clearly a reference to the mines at Carbon.

In 1869 he said, in speaking of a trip from Fort Sanders to Fort Fred Steele: "Our course was along the Overland Stage Road just at the base of the mountains, on the south side of the Laramie Plains, from 5 to 20 miles south of the Union Pacific Railroad line."[3]

In his report for 1870 Hayden used "Laramie Plains" both in the limited and in the broader sense. Thus the statement that the "entire surface of the plain east of the Medicine Bow forms one vast pasture ground" implies clearly that there are two portions of the plain, one east and one west of the Medicine Bow River.[4]

The statement that the Laramie Plains "is usually understood to extend westward almost to the Medicine Bow River"[5] is clearly the

[1] *Annual Report of the Commissioner of the General Land Office* for 1871, 1872, p. 271; see also *Fourth Annual Report*, U.S. Geological Survey of Wyoming (1871), p. 251.

[2] *Proceedings of the American Philosophical Society*, Vol. X (1868), p. 467; [*Second Annual Report*, U. S. Geological Survey of the Territories, 1868] *Report of the Commissioner of the General Land Office* for 1868, 1868, p. 233; *First, Second*, and *Third Annual Reports*, U. S. Geological Survey of the Territories for 1867, 1868, and 1869, p. 80. This statement should be compared with the statement on p. 89 of the last report (p. 242 of the original Land Office report), where it is stated that the Laramie Plains are 60 miles from east to west. This width, when compared with Thomas' statement, places the western edge of the Laramie Plains near the North Platte River.

[3] *Proceedings of the American Philosophical Society*, Vol. XI (1869), p. 34.

[4] *Fourth Annual Report*, U. S. Geological Survey of Wyoming and Contiguous Territories (being a *Second Annual Report of Progress*), (1871), p. 79.

[5] *Ibid.*, p. 121.

restricted usage, unless it is held that the expression "North Platte River" was really intended instead of Medicine Bow River—a view which is sustained by the width of 50 miles from east to west which is given for the plain, and by other expressions given in the context; while in the statement that the North Platte River cuts its "way through immense canyons between the North Park and the Laramie Plains," and again, "the Medicine Bow and the two Laramies . . . . take their rise in the elevated snow-capped mountains on the south side of the Laramie Plains,"[1] the term is clearly used in its broader sense. In all of the geological references the term is used in its broader sense.

Hague, in speaking of the western limit of the Laramie Plains, says in 1878:

> To the northwest, however, the Plains are not entirely rimmed in, the open country stretching for a long distance without marked geographical boundary. For most purposes, however, it will be well to regard the western boundary of the Plain as limited by the Como Ridge just north of the Medicine Bow Range. . . . . As thus defined, the Laramie Plains measure at least 80 miles in length by about 30 miles in breadth.[2]

This is clearly the restricted usage, but it recognizes a broader usage. It is in this broader sense that the phrase "Laramie Plains" is used by the present writer.

HAYDEN'S INVESTIGATIONS

Hayden studied the exposures in the Laramie Plains in 1867, 1868, 1870, and 1875. In the fall of 1867, after the completion of the field-work on the geology of Nebraska Territory, he passed over the Front Range into the Laramie Plains and proceeded along the Overland Stage Road as far west as the now famous Rock Creek locality.[3] He then proceeded by way of the Overland Stage Road to South Bowlder Creek, a short distance north of Denver, thence northward

[1] *Ibid.*

[2] *Geological Exploration of the Fortieth Parallel,* Vol. II (1877 [1878]), p. 73.

[3] *American Journal of Science,* Second Series, Vol. XLV (1868), pp. 101, 102 (letter to J. D. Dana, dated Cheyenne City, Dakota Territory, October 31, 1867); *ibid.*, pp. 199, 200, 204, 205; *Final Report,* U. S. Geological Survey of Nebraska (1872), pp. 46, 54, 55. Hayden states that the last report was printed without revision in exactly the same form, except for certain omissions, as it was transmitted to the commissioner of the General Land Office on March 1, 1868.

to Cheyenne along the east base of the mountains. In this investigation he recognized in the Laramie Plains Cretaceous beds up to and including the Fox Hills,[1] and found that "at Rock Creek, about 40 miles west of the big Laramie River, the lignite beds overlap[2] the Cretaceous."[3] He collected from these lignite beds "in the Laramie Plains . . . . two species of plants, a *Populus* and a *Platanus*, specifically identical with those found on the upper Missouri."[4] This collection of plants was studied by Lesquereux[5] and listed as from "Rock Creek, Laramie Plains." As knowledge of the flora progressed, Lesquereux referred this collection to the same horizon as the Carbon plant-beds,[6] and in the light of present knowledge there can be no reasonable doubt that they came from the same formation. After his field-work of 1867, Hayden announced the doctrine, entirely natural from his knowledge of and experience with the coal-bearing beds in the Dakotas, eastern Montana, and northeastern Wyoming, that all the coal-bearing beds of the Rocky Mountain region are younger than the Fox Hills. He thus included certain Upper Montana coal-bearing beds which in the region of Rock Creek directly underlie the Upper Laramie strata containing the plants referred to above.

In 1868 Hayden, continuing the "Survey of the Territories," extended his investigations of the Laramie Plains. He proceeded from Fort Sanders along the Overland Stage Road as far as Pass Creek, and then turned north to Fort Steele. Returning to Fort Sanders, he proceeded to examine the geology along the line of the Union Pacific Railroad from Fort Sanders westward.[7] In his account

[1] *Final Report*, Geological Survey of Nebraska (1872), p. 55.

[2] From the usage of the word "overlap" through Hayden's writings, it is believed that he used the word as a synonym of "overlie," and not in its present technical geologic sense.

[3] *American Journal of Science*, Second Series, Vol. XLV (1868), p. 205.

[4] *Ibid.*, p. 204; see also p. 101; and *Final Report*, Geological Survey of Nebraska (1872), p. 55.

[5] *American Journal of Science*, Second Series, Vol. XLV (1868), p. 205; [*Third Annual*] *Preliminary Field Report*, U. S. Geological Survey of Colorado and New Mexico (1869), pp. 95, 96.

[6] *Fifth Annual Report*, U. S. Geological Survey of Montana for 1871, 1872, p. 306.

[7] [*Second Annual Report*, U. S. Geological Survey of the Territories, embracing Wyoming] *Report of the Commissioner of the General Land Office* for 1868, 1868, pp.

of this trip he describes the exposures along the Overland Stage Road, and among the beds which he studied, and then referred to the Lignitic, there are none which are now known to belong to the Lower Laramie, or the "true Laramie" of recent geologic literature. He states that he found "great quantities of deciduous leaves" (which "indicate the Tertiary age of the rocks, and also show that they jut far up close to the foothills of the mountains") in strata which are now known to be Upper Laramie and which in that immediate region rest unconformably on all beds down to the Dakota. The preponderance of evidence indicates that it was from this locality on the overland trail just west of Rock Creek that he obtained the leaves identified by Lesquereux as from "Rock Creek, Laramie Plains," which are clearly Upper Laramie. He also examined the strata and collected leaves from the Upper Laramie beds at a point just north of Medicine Bow stage station (now Elk Mountain post-office). The Upper Laramie beds at this point rest on the Lewis shales, which because of the coal-bearing character of the underlying Mesa Verde beds Hayden at this time included in his Tertiary.

Along the railroad he found only Cretaceous outcrops until he reached a point 5 miles east of Como, where he reports a sandstone "with fragments of stems and leaves," which he at first thought was probably lower Tertiary.[1] Continuing, he says:

> From a point about 10 miles west[2] of Como to St. Mary's Station . . . . the Tertiary formations occupy the country with the peculiar sands and sandstone and clays, and numerous coal-beds. The most marked development of the coal-beds is at Carbon Station, about 80 miles west of Laramie Station. . . . . In the beds above and below the coal are thousands of impressions of deciduous leaves, as *Populus*, *Platanus*, *Tilia*, etc. Some of the layers of rocks 2 to 4 inches in thick-

242–49; reprinted in ***First***, ***Second***, and ***Third Annual Reports***, U. S. Geological Survey of the Territories (1873), pp. 89–96; ***Proceedings of the American Philosophical Society***, Vol. XI (1869), pp. 28–38, 54, 55.

[1] This sandstone is low in the Cretaceous, and on second thought Hayden referred it to the Cretaceous (***Proceedings of the American Philosophical Society***, Vol. XI [1869], p. 370). He re-examined the locality in 1870 and again referred it to the Cretaceous.

[2] In the original this reads "east," but when compared with the statement that the Cretaceous rocks continue to a point about 5 miles east of Como, and when considered in connection with the general lay of the country it undoubtedly should be "west." It is changed to "west" in the reports for 1870 ([***Fourth Annual***] ***Preliminary Report***, U. S. Geological Survey of Wyoming [1871], p. 164).

ness are wholly composed of these leaves in a good state of preservation, and so perfect are they that they could not have been transported any great distance.[1]

The extreme western portion of the area described by Hayden in the above as occupied by the Tertiary—that is, the region in the immediate vicinity of St. Mary's station—is underlain by Lower Laramie strata, but along the railroad the beds are almost entirely covered by Quaternary débris. The beds actually studied by Hayden in this area, and upon which he based his opinion, are certainly wholly Upper Laramie.

In summarizing his results in a letter written from the field to the commissioner of the General Land Office, Hayden shows that he had already begun to suspect that his decision that all coal-bearing beds in this region are Tertiary is not well founded. In the same letter he announces his unqualified belief that the Tertiary beds—that is, those yielding the plants at Carbon, Medicine Bow stage station, and Rock Creek—are unquestionably conformable with the Cretaceous. He says:

We have taken the position also that the coal-bearing beds of the Laramie Plains are of Tertiary age, although some marine fossils are found in strata connected with the coal. There may be some thin seams of impure coal in the upper Cretaceous beds. . . . . I can find no want of conformity between the Tertiary and Cretaceous beds, and indeed so gradually and imperceptibly do the Cretaceous beds pass up into the Tertiary that I have not been able to determine the line of separation.[2]

In a review of the same subject before the American Philosophical Society on February 19, 1869, Hayden clearly shows that he regards the Carbon locality as not only the most important locality in the Laramie Plains, but as the connecting link between the great Lignitic group of the Missouri River (which he then, because of the flora, regarded as Miocene) and the coal-bearing deposits of Wyoming. He says, in summarizing his geological observations at this time:

The Cretaceous formations occupy the country for 60 miles from Laramie City to Lake Como. Genuine Jurassic beds . . . . are here exposed for a short

[1] [*Second Annual Report*, U. S. Geological Survey of the Territories] ***Annual Report***, Commissioner of the General Land Office for 1868, 1868, p. 249; ***Proceedings of the American Philosophical Society***, Vol. XI (1869), p. 37.

[2] *Annual Report*, Commissioner of the General Land Office, for 1868, 1868, p. 253; *First, Second,* and *Third Annual Reports*, U. S. Geological Survey of the Territories (1873), p. 100.

distance. Cretaceous beds, mostly No. 2, appear again west of Como. Miocene coal-beds overlay the Cretaceous just before reaching Carbon Station, 80 miles west of Laramie. At Carbon, where they are exposed to view, impressions of fossil leaves occur in the greatest abundance. The species are few, and nearly all of them identical with those described by Dr. Newberry, from the Miocene Tertiary beds of the Upper Missouri. Some strata consist almost entirely of leaves, in a fair state of preservation, as if they had not been subjected to a great deal of drifting prior to deposition. Indeed the trees themselves must have grown near the spot, to shed their leaves in such great abundance, just as we find leaves accumulated now in muddy bottoms. Dr. Newberry has identified from this locality, *Populus cuneata*, *Populus Nebrascensis*, *Platanus haydeni*, and an undescribed species of *Cornus*. The Wyoming Coal Company's shaft, sunk at this station to reach the coal, has descended nearly 60 feet through a considerable thickness of bluish-black arenaceous clay, in rather thick layers, upon the surface of which are great quantities of *Populus* and *Platanus*. Very nearly the same species are described [found] throughout a great thickness of these Tertiary beds, and the evidence seems to be pretty clear that the vegetation was nearly uniform throughout the period of the deposition of the coal strata.[1]

Although Hayden did not work in this region in 1869, he referred to the area in his "Review of the Leading Groups" in his report for this year. In this account he definitely refers the beds on the Laramie Plains (and for the first time) to "the great lignite group,"[2] and indicates that in the region west of the Laramie Plains he considers it limited above by the Washakie group.

In 1870 Hayden, starting at Cheyenne, traveled northward to the Platte River, and thence westward along the old emigrant road through Smith Pass to Fort Bridger. Returning, he followed the Overland Stage Road up Bitter Creek Valley through Bridger Pass to Laramie City, and then re-examined the geology along the line of the railroad west of that point. In the report for this year he still refers some of the Montana and older Cretaceous sandstones containing coal-beds to the Tertiary, but there is evidence of a growing suspicion that they may be Cretaceous.[3] He even goes to far as to say: "The evidence seems to point to the Cretaceous age of the coal group

[1] *Proceedings of the American Philosophical Society*, Vol. XI (1869), pp. 54–55.

[2] "Along the line of the Union Pacific Railroad we find in the Laramie Plains a most extensive exhibition of the great lignite group."—[*Third Annual*] *Preliminary Field Report*, U. S. Geological Survey of Colorado and New Mexico (1869), p. 90.

[3] [*Fourth Annual*] *Preliminary Report*, U. S. Geological Survey of Wyoming for 1870, 1871, p. 165.

in Weber Valley."[1] He strongly emphasizes in this report the importance of the Laramie Plains localities, particularly Carbon, in the determination of the question of the age of these beds. He certainly singles out Carbon as the one locality at which the age can be fixed, regarding the flora as there developed as the important connecting link between the coal-bearing beds of Wyoming and those of the Missouri River region. He says:

> The most important coal-mines are located at Carbon. No shells have ever been observed in connection with the coals, but thousands of impressions of deciduous leaves are found. It is important to fix the age of the coal-beds in any one locality. So far as we can determine, the coal-beds of the Laramie Plains are of Eocene age, although the plants are more closely allied to those of the Miocene period in the Old World.[2]
>
> So far as the Evanston coal-mines are concerned . . . . I discovered a magnificent series of fossil leaves, among which Dr. Newberry informed me he had detected species identical with those occurring in connection with the coal-beds of the Laramie Plains and on the upper Missouri.[3]

In 1872 Hayden directed Lesquereux to make explorations in Colorado and Wyoming with a special "view to positively ascertaining the age of the Lignitic formations, either from data obtainable in collecting or examining fossil vegetable remains or from any geological observations which I [he] should be able to make."[4] In this examination he visited Rock Creek and Carbon. At Rock Creek he failed to find the locality from which Hayden obtained his leaves, finding only outcrops yielding characteristic upper Cretaceous marine forms.[5] He thus anticipated, as Hayden had before, and perhaps to a more complete degree, anticipated by the finding of Fox Hills sandstones on Rock Creek,[6] the conclusions reached many years later by Drs. Stanton and Knowlton[7] at this locality. At Carbon he included with the Lignitic, because of the presence of the fucoid *Helemynites*, which he then supposed to be characteristic of the Lignitic,

[1] U. S. Geological Survey Report, *loc. cit*, p. 167.

[2] *Ibid.*, p. 164. [3] *Ibid.*, p. 167.

[4] *Sixth Annual Report*, U. S. Geological Survey of the Territories for 1872, 1873, p. 317.

[5] *Ibid.*, p. 330.

[6] *Bulletin of the Geological Society of America*, Vol. VIII (1896), pp. 137–43.

[7] [*Fourth Annual*] *Preliminary Report*, U. S. Geological Survey of Wyoming (1871), p. 79.

but which is more abundant in the upper Montana,[1] certain Cretaceous coal-bearing sandstones which are now known to be Mesa Verde. With this exception, Lesquereux studied only beds of Upper Laramie age, making large collections from the immediate vicinity of the mines. He studied and recognized the sea-beach character of the conglomeratic sandstones just west of Carbon, which are now recognized as the base of the Upper Laramie. This conglomeratic sandstone contains pebbles now known to have been derived from the underlying Cretaceous and older rocks, and indicates an immense unconformity. His report, in the light of present knowledge, is extremely suggestive. Thus he refers the beds at Carbon to the "upper Lignitic" and suggests the equivalence of the conglomeratic sandstone just mentioned with "that of the upper member of the Lignitic of Colorado" (possibly meaning beds since reported as the Arapahoe).

Two reports by Hayden, clearly written before the final adoption of the word "Laramie," complete the history of the development of his knowledge and belief in this critical period. In a "Brief History of the Lignitic Group"[2] Hayden states that "the Lignitic group of the Northwest [is] believed to be continuous southward with the Colorado and Laramie beds." In this report Hayden finally acknowledges the presence of coal in beds of true Cretaceous age, saying:

> One fruitful source of difference of opinion has been in the misunderstanding in regard to the different horizons of the coal strata of the West. That there are important coal-beds in rocks of well-defined Cretaceous age cannot be disputed, and I have long since yielded that point. What we wish to show more clearly is that there exists in the West a distinct series of strata which we have called the Lignitic group, and that it is entirely separate paleontologically and geologically from a great group of strata in the lower Cretaceous,[3] and perhaps extending down into the Jurassic, which contain a great number of thick and valuable beds of coal. It is not necessary to discuss the question whether the term Lignitic should be applied to either or both groups. I have used the term Lignitic for the upper

[1] Hayden recognized this in 1875 (*Bulletin*, U. S. Geological and Geographical Survey of the Territories, Vol. I [1876], p. 404), and it has since been abundantly proven.

[2] *Eighth Annual Report*, U. S. Geological Survey of the Territories for 1874, 1876, pp. 19–27.

[3] The phrase "lower Cretaceous" is not here used in the present technical sense (Lower Cretaceous or Comanche beds were unknown to Hayden) but rather in the sense of underlying.

group without reference to the quality of the fuel simply to distinguish it from the other great group of older age, the age of which is not questioned. . . . . It is well known that I have held with some tenacity the opininon that the coal formations of the West are of Tertiary age; and I still regard the Lignitic group proper as transitional or lower Eocene.

The name "Laramie beds" is used in the first of the above quotations in a simple geographic sense, but it clearly indicates what to Hayden was a most natural term. In the Hayden report for 1873, published in 1874, Marvine, in discussing the exposures in the vicinity of Denver and Golden, Colo., used the geographic name "Colorado Lignitic group,"[1] with the suggestion "that the extended explorations of Hayden and others would seem to prove almost conclusively that the Colorado Lignitic group is the direct southern stratigraphical equivalent of the Fort Union group of the upper Missouri." But he adds the precautionary statement : "When all the facts are known, they may develop some new ideas as to geological transitions." The Colorado beds in the above clause from Hayden's *History of the Lignitic Group* are clearly the same as the "Colorado Lignitic group" of Marvine, and there was thus at this time two natural names for the Lignitic group as developed in Wyoming and Colorado—the Colorado group and the Laramie group. When Hayden and King agreed to use the term "Colorado group" as an appropriate name for the combined Fort Benton, Niobrara, and Pierre,[2] the term "Laramie group" was left as the natural and appropriate designation.

In "Notes on the Lignitic Group of Eastern Colorado and Portions of Wyoming," which appears to have been the last paper written by Hayden on this subject before the adoption of Laramie, he states that

throughout the Lignitic proper, that is the portion occurring above the Fox Hills group, I have never found any true nonconformity. That there may be in some places an interrupted sequence in the beds is quite possible. . . . . That there have been many oscillations of the surface, that it has been alternately above and below water many times, may be inferred from the numerous coal-beds. In the aggregate, there could hardly have been any marked interruption in the sequence of the deposition, even up to the summits of the highest Tertiary, though between

[1] *Seventh Annual Report*, U. S. Geological and Geographical Survey of the Territories for 1873, 1874, p. 107.

[2] *Report of the Geological Exploration of the Fortieth Parallel*, Vol. I (1878), p. 298.

the Lignitic group and the more modern Tertiaries, as the Washakie, Green River, and other fresh-water groups, there is at this time a true nonconformity. . . . . If we could look beneath the horizontal strata of the Washakie group between Separation and Bitter Creek, or under the Bridger and Green River groups along the immediate line of the railroad, we might find localities where the sequence of the beds is not interrupted, and yet, in the immediate vicinity of the mountain-ranges, as the Uintah, for example, the modern fresh-water Tertiaries rest unconformably on the older rocks.[1]

This clearly shows that in this region Hayden regarded the Lignitic as limited below by the Fox Hills and above by the Washakie (Wasatch or Vermilion Creek) group. That he had already begun to suspect the existence of a break at the base of the Laramie is suggested by the following statement:

It is evident that in many localities, and possibly throughout eastern Colorado, a considerable portion of the Upper Fox Hills group is wanting. Sometimes the Lignitic group is deposited on No. 4 or No. 3 Cretaceous. Therefore there is undoubtedly a conformable interrupted sequence; in other words, while the Lignitic group appears to conform to the underlying beds, there really are wanting hundreds, and perhaps thousands, of feet of strata which at some other locality in the West may exist.[2]

HAGUE'S STUDIES

Another line of evidence is perhaps needed to give the complete historical background necessary to reach a correct conclusion in this question of the origin and definition of the term "Laramie." There are a number of reasons for believing that not only was the term "Laramie," as has been shown, the most natural name for Hayden to suggest when asked by King for an appropriate term,[3] but it was also the name which was independently suggested to King by Hague.[4]

[1] *Bulletin*, U. S. Geological and Geographical Survey of the Territories, Vol. I, No. 5 (January 8, 1876), p. 410.

[2] *Ibid.*, p. 404.

[3] Dr. A. C. Peale has informed me that he has in his possession a letter from King to Hayden, bearing a date later than November 15, 1875, requesting that he, Hayden, propose a name for the Lignitic.

[4] Verbal statement by Mr. Hague to the author, corroborated by the use of the term "Laramie" on a map issued by the King Survey, November 15, 1875. See *American Journal of Science, Third Series*, Vol. XI (1876), p. 161; *Bulletin*, U. S. Geological Survey of the Territories, Vol. III (1877), p. 182; *Bulletin No. 82*, U. S. Geological Survey (1891), p. 147.

Mr. Hague studied the region of the Laramie Plains in the fall of 1872. At the Rock Creek locality he reports and maps only Fox Hills strata,[1] although he states he did not see the coal openings reported by Hayden, near one of which typical Upper Laramie plants have since been found,[2] thus confirming the early observations of Hayden. Carbon was therefore the only locality on the Laramie Plains where Hague recognized Laramie strata. The strata at this point which he refers to the Laramie are clearly Upper Laramie.

In opening the discussion of the Carbon locality, Hague says:

> Geologically the place has also received considerable attention in examining the question of the age of the Wyoming coals. There would appear to be but little doubt that the beds belong to the Laramie division of the Cretaceous sandstone.

It would certainly have greatly simplified one point in the consideration of this greatly involved subject if Hague had said here, as he has since said in conversation, that the beds are called Laramie because of their exposure at this point on the Laramie Plains. It is unquestionably the only point on the Laramie Plains where the Laramie beds were recognized and critically studied by the King Survey, and King was too keenly alive to the absolute importance of a geographic origin for geologic names (the names being derived from type localities at which the beds were well exposed and could be unquestionably defined) to have permitted the adoption of, or even seriously considered, a term not definitely fixed in this way. His feeling in the matter is clearly shown by the fact that he refused to use the prior name "Wasatch" solely because at what he considered the type locality of Hayden, the Wasatch Mountains, the beds were not fully and typically exposed. He considered this sufficient reason to reject this name and to apply a new name, "Vermilion Creek group," taken from the locality where the beds were well exposed and could be fully defined.[3] In the light of these facts, it is clear that the

[1] *Report of the Geological Exploration of the Fortieth Parallel*, Vol. II [1877 (1878)], pp. 86–87.

[2] *Bulletin of the Geological Society of America*, Vol. VIII (1896), pp. 141, 142. The field-work of 1906 practically connected this locality with that at Carbon and completely confirmed the provisional reference by Dr. Knowlton.

[3] *Report of the Geological Exploration of the Fortieth Parallel*, Vol. I (1878), p. 354. King's belief that the name "Wasatch" was taken from the Wasatch Mountains is shown by a careful consideration of Hayden's writings to have been unfounded. The type

rhetorical doubt expressed in the above sentence from Hague's report relates solely to the point whether or not these beds were Cretaceous. No one has questioned or could question that they were Laramie, since they were the exposures which justified the use of the name. The question, as clearly shown by the preceding section and ensuing discussion, was solely the one of geologic age. Lesquereux, from large collections of plants at this point, had asserted that the beds were undoubtedly Miocene. Starting with this rhetorical question, Hague proceeds to "determine the true horizon of these beds," namely that they are Cretaceous, by "tracing out their relations with the great sandstone formation [Fox Hills] which forms all the higher ridges of the region," and by comparing "the strata with other similar localities." He then states that the "beds at Carbon occupy a broad, irregular-shaped basin, the rocks on the west, south, and east all dipping in toward the center, surrounding it completely on three sides." He reports that on the west the beds of Simpson Ridge may be traced "passing conformably under the level coal-bearing strata of the valley;" that on the east the same coal-bearing sandstones are underlain by beds preserving the same dip, and to the south the beds "appear to be perfectly conformable with the basin strata." In other words, in his opinion the conformability of these Laramie beds with the underlying strata at this point is completely demonstrated.[1]

locality, as shown by the description of Hayden, extends from Carter, Wyo., to the Narrows, on Weber River, 7 miles below Echo City, Utah. The name is derived from Wasatch Station on the Union Pacific Railroad in Summit County, Utah, situated about midway between Carter and The Narrows. In this section the beds are very fully and completely exposed. See in this connection *Professional Paper No. 56*, U. S. Geological Survey (1907), pp. 87, 88.

[1] Hague's conclusion is clearly based wholly on the exposures (1) on the east flank of Simpson Ridge immediately southwest of Carbon, and (2) those along the railroad just east of town. The basal sandstones of the Upper Laramie outcrop along the east flank of Simpson Ridge with so nearly the same strike as the "Fox Hills sandstones" of the ridge (which are really Mesa Verde and several thousand feet below the top of the Montana) that from the exposures at this point one would certainly not suspect an unconformity except from a very critical study of the source of some of the contained pebbles. Immediately north and south of these exposures there is, however, a very marked angular unconformity between the Upper Laramie and the underlying Cretaceous strata. At the point where Hague reported conformity the upper 2,000 feet of the Lewis and all of the Lower Laramie is wanting. A few miles to the south the same Upper Laramie beds rest on highly inclined rocks of Cretaceous age, down to and including the Dakota. East of Carbon, Hague fixed the base of the Laramie at

Taking up then the consideration of Lesquereux's conclusions, he decides that the age of the deposits

rests either on the fossil plants which they contain or upon their stratigraphic position, and where such testimony disagrees it would seem that the latter must necessarily receive the greater weight. . . . . Professor Lesquereux, notwithstanding he feels so positive as to the Miocene age of the Carbon beds, does not hesitate to place them below the Green River series, giving them a position in relation to the latter horizon which few geologists will be disposed to dispute, and which the geological maps and sections accompanying this report conclusively prove. In the second chapter of this volume it will be shown that the Green River beds are undoubtedly of Eocene age, that they are . . . . underlaid by a heavy thickness of the Vermilion Creek series, also Eocene, and that the latter overlies unconformably beds occupying the same horizon as the Carbon formation, which we regard as of upper Cretaceous age.

CROSS'S REDEFINITION

Hayden and King clearly adopted the word "Laramie" for the beds between the marine Montana Cretaceous and Wasatch or Vermilion Creek Eocene. The next important advance in the knowledge of this subject resulted from the work of Cross and Eldridge in the Denver region. They found here that the Laramie as mapped by the Hayden Survey was broken by an immense unconformity, succeeded by a second one of minor importance.

Cross was thus confronted with the difficulty of determining whether the beds above the unconformity, or those below the unconformity, should most appropriately be called Laramie. After carefully considering the writings of King, and finding his statement that the Laramie included "that series of beds which conformably overlie the Fox Hills," Cross quite naturally decided that the term "Laramie" should be applied only to the beds below the unconformity. The fact that detailed work has now shown (1) that all the Laramie beds known on the Laramie Plains at the time of the adoption of the word "Laramie" are "Upper Laramie," (2) that, although they were believed to be entirely conformable with the underlying beds by all who had examined them, they are in fact separated from them by a great break, and hence that the statement of conformability in King's definition is without determinative value in this connection, because

the base of the Upper Laramie, and included in the Fox Hills beds of Lower Laramie age which are exposed at this point, thus absolutely and conclusively limiting the Laramie at this point to the Upper Laramie.

based upon erroneous observations and conclusions, while proving that Cross's conclusion in this matter was incorrect, does not in any way detract from the great credit which is justly due him as the discoverer of this great break. Cross's error in this one particular of the restriction of the word "Laramie" to the lower beds was not due to his own observation, but to his acceptance of the work of others. This redefinition, instead of helping the already perplexed Laramie situation, but added one more complexity to it and resulted in the entirely incorrect and inappropriate application, to the Lower Laramie, of such terms as "Laramie proper," "original Laramie," "true Laramie."

The restriction of the term "Laramie" to the beds below the unconformity, based on Cross's studies in the Denver region, proves in its ultimate analysis to be an attempt to redefine a geologic term from the exposures and relations at a point almost 200 miles from the locality from which the geographic name was derived and at which the beds are most excellently exposed. This redefinition was based entirely on an abstract consideration of a statement based in part on erroneous observations, at a time when no critical re-examination had been made of the conditions in the region, whence the name was derived, and when nothing was known of the true relations in that area. We thus have the scientific anomaly of a geologic name derived from exposures in a certain region, all of which belong to one group of strata, redefined in a different region and applied to an entirely distinct group of beds. This is clearly indefensible and absolutely at variance with the fundamental principles of geologic nomenclature. It in effect gives a result which is no better than a lithologic term, and certainly not as appropriate. The whole case but emphasizes the absolute necessity of a geographic place origin for geologic names in order to finally guard against misinterpretations, incorrect statements, and conclusions by the authors of such names.

SUMMARY AND CONCLUSIONS

1. The name "Laramie" is derived from the Laramie Plains in eastern Wyoming. As commonly used in the early seventies, this included the plains region extending from the Front Range to and slightly beyond the North Platte River.

2. The most important locality on the Laramie Plains at this time was Carbon. It was not only a noted paleontological locality, but was the most important coal-mining town on the Union Pacific Railroad at that time. It was the only locality on the Laramie Plains where the King Survey critically examined and distinctly delimited the Laramie beds. The Hayden Survey recognized Laramie strata at another point on the Laramie Plains, Rock Creek, but regarded the Carbon locality, including its southern extension containing the plants labeled from "Medicine Bow stage station," as affording better and more complete exposures.

3. It was the practice of the Hayden and King surveys to name formations and groups from localities where the beds were regarded as typically exposed. While King and Hayden did not always definitely state that a name was derived from a certain locality, the source of the name can in all cases be completely inferred from the context. Thus King used Green River, Bridger, Uinta, Truckee, and other names without saying the name was derived from such and such a locality, while he distinctly states the source of Vermilion Creek, Weber, and other names. King's strong feeling in this matter of a type locality is shown by the fact that he refused to use the prior name "Wasatch" and adopted the new name "Vermilion Creek" simply because at what he considered Hayden's type locality the beds were not completely and typically exposed. The state of feeling at this time is further shown by the fact that the name "Laramie" was proposed and adopted as an exact synonym of Hayden's "Lignitic" as defined by him in Wyoming and Colorado. If merely a general term without a type locality was desired, the term "Lignitic" would have served all purposes. The change was clearly based on a recognition of the necessity of having a geographic type locality. From the above facts it follows irresistibly that the type locality of the Laramie is Carbon, on the Laramie Plains.

4. A critical consideration of investigations of Hayden and King parties in this region shows that the actual Laramie exposures studied by them are separated from the Cretaceous by an unconformity of great magnitude. At Carbon Hague particularly and minutely included only the beds above the break. Both Hayden and Hague regarded these beds as entirely conformable with those beneath;

hence the statement by King that the Laramie beds are those which conformably overlie the Fox Hills, while correct according to the existing knowledge, is not correct at the type locality, and therefore without determinative value in this connection. It but illustrates anew the absolute necessity of a type locality to afford means of finally and conclusively correcting any inaccurate statements or conclusions of the author or authors of a geologic name. Strictly considered, the term "Laramie" therefore can appropriately be applied only to the beds above the great unconformity and—fixing an upper limit in part from our present knowledge—below the Fort Union.[1]

5. The attempt to redefine the term "Laramie" from the exposures in the Denver region, some 200 miles from the type locality, is therefore not defensible. It results in the scientific anomaly of applying the term "Laramie" to a series of beds entirely distinct from those at the type locality on which the name was based. It completely robs the name of all geographical significance, and gives to it even less meaning or appropriateness than a mere lithologic term such as "Lignitic."

6. While strictly speaking the name "Laramie" can be appropriately applied only to the upper beds (Upper Laramie), and it cannot with any propriety be restricted to the lower beds (Lower Laramie), the consideration that it was proposed for the beds between the Wasatch and the marine Montana Cretaceous, and has been most commonly and extensively used in this broad sense, has led to the suggestion that the retention of the name in this original sense will cause the least confusion, and that it therefore might be expedient to define the Laramie as that series of beds occurring between the marine Montana Cretaceous and the Fort Union.

[1] At Evanston there are several reasons for believing that the base of the Wasatch of Hayden contains representatives of the Fort Union, Puerco, and Terrejon. Between the Laramie and the Coryphodon-bearing Wasatch are some 4,000 feet of strata separated from the Coryphodon-bearing beds by an unconformity. At Black Buttes beds now known to be Fort Union (Knowlton, *Bulletin of the Geological Society of America*, Vol. VIII [1896], p. 145) were referred by King to the Vermilion Creek. It therefore seems not only logical, but in accord with the original usage, to define the upper limit of the Laramie as the Fort Union. The Washakie beds which Hayden regarded as, in this region, limiting the Lignitic above (*Third Annual Report*, U. S. Geological Survey, Colorado, New Mexico, 1869, p. 90) and which were included by King in his Vermilion Creek, are the beds from which Knowlton reports distinctive Fort Union plants at Black Buttes.

In connection with this suggestion of expediency, it should be pointed out that the continued use of this term in the "catchall" sense is wholly at variance with the abundance of strong and wholly logical reasons for the restriction of the term "Laramie" to the "Upper Laramie" shown by the historical considerations already presented. If the point of confusion is regarded as one of great importance, it might be worth while considering the entire abandonment of the term "Laramie."

In either case a new name is required for the beds here referred to as Lower Laramie. Many considerations suggest that this name should come from the region of the Laramie Plains. This would be historically appropriate in many ways, and would result in placing the type locality of both the upper and the lower portions of the beds which have been called Laramie in the broad sense, in the same section. There are reasons for believing that the enormous development of Lower Laramie beds in the western part of the Laramie Plains near the mouth of the Medicine Bow River, or, as it is more commonly called by the local people, "The Bow," where there is relatively very little evidence of a break between the upper and lower beds, more completely represents the Laramie deposition than at any other point now known. These considerations make the "Bow formation" or "group" a very appropriate designation for these lower beds. On the other hand, the fact that the region of Golden has been made classic in connection with the "Laramie problem" by the studies of Cross, Eldridge, Knowlton, and others, raises the question whether the name "Golden formation" or "group" might not be a more appropriate name.

The discovery of this great unconformity at all points that have been critically examined over an area 1,000 miles north and south and 250 miles east and west, the fact that it occurs on both the east and west sides of the Front Range of the Rocky Mountains, and its great magnitude, all make it one of the important mile-posts in the geologic history of western North America. All these considerations suggest anew the first conclusion of Cross in the Denver region that this unconformity marks the dividing line between the Cretaceous and Eocene in this region. On this basis the arrangement of groups immediately above and below the great break would be as follows:

Lower Tertiary or Eocene	Green River	
	Knight or Coryphodon beds[1]	Wasatch
	Fort Union (Puerco and Terrejon)[2]	Wasatch
	Laramie	
	Unconformity	
Upper Cretaceous or Platte series	"Lower Laramie"	
	Montana	
	Colorado	

[1] The name "Knight" has been proposed for the upper part of the Wasatch containing Coryphodon remains. It is taken from Knight Station, a point near the locality where fossils belonging to this genus were first found in North America, and where the typical upper Wasatch is extremely well developed. Certain considerations suggest that the Knight formation may be an exact synonym of King's Vermilion Creek formation, but as the writer has not had the opportunity to examine King's type section he has proposed the provisional name "Knight" pending a study of the Vermilion Creek section. See *Professional Paper 56*, 1907, pp. 87–89, 92–96.

[2] In the Evanston section, between the beds belonging to the Laramie (Carbon) group and the Coryphodon-bearing Wasatch, are 4,000 feet of strata which have the stratigraphic position of the Fort Union and Puerco. These are here separated from the Coryphodon-bearing portion of the Wasatch by an unconformity of much less magnitude and importance than that at the base of the Laramie (Carbon) beds.

THE CHARACTERISTICS OF VARIOUS TYPES OF CONGLOMERATES[1]

GEORGE R. MANSFIELD
Harvard University

In the prosecution of a recent study of the Roxbury Conglomerate (Boston, Mass.), the writer found himself in need of criteria by which to determine the mode of origin of that formation. A critical examination was therefore made of the published descriptions of conglomerates in many parts of the world and belonging to many geological ages, in the hope of discovering characteristics sufficiently marked to distinguish one type from another. The data collected and the conclusions derived therefrom have recently been published in detail.[2] The present paper is a brief summary of the results of the investigation.

Five general types of conglomerate were considered, namely: marine, fluviatile, estuarine, lacustrine, and glacial. In addition to these, another type was studied, commonly known as crush-conglomerate, but really pseudo-conglomeratic in its nature. The fact was recognized that many conglomerates are the product of the combined action of several conglomerate-forming processes, but the results of each process were classified separately.

Among the formations taken under consideration were: the Cretaceous formation of Texas, as described by Hill;[3] the Pottsville Conglomerate; non-marine formations in India, Persia, Great Britain, and the United States; the Devonian of Pennsylvania and Maryland, as described by Willis;[4] the Newark formation as described by Russell;[5] glacial deposits of the Quaternary period in the United States and Europe; ancient glacial deposits in India, Australia, South Africa, and Norway; and crush-conglomerates in the Isle of Man and Argyllshire.

[1] Read before the Geological Society of America, December 28, 1906, New York.

[2] Museum of Comparative Zoölogy, *Bulletin No. XLIX*, Geological Series, 8, 1906.

[3] R. T. Hill, U S. Geological Survey, *Twenty-first Annual Report*, 1901, pt. 7.

[4] Maryland Geological Survey, 1902, Vol. IV, pp. 21–93.

[5] U. S. Geological Survey, *Bulletin No. 85*, 1892.

The data collected from these various sources were arranged in accordance with the following scheme:

Matrix.—Kind of material; size of grains (coarse or fine, uniform or varied); shape of grains (angular, subangular, or rounded); arrangement of grains (orderly or disorderly, well stratified, rudely stratified, or unstratified); cement (argillaceous, siliceous, calcareous, or ferruginous).

Pebbles.—Kind of material; size of pebbles (large or small, uniform or varied, gradation in any particular direction); markings (facets, polish, striation); deformation (distortion, tension cracks, fracture); arrangement (well stratified, rudely stratified, unstratified).

Color.—General tone of the rock; relations to matrix; relations to pebbles.

Characteristics of bedding.—Uniform series grading into finer beds, thickness and extent; variable series (lenses of coarser and finer materials, false-bedding and local unconformities, ripple-markings, sun-cracks, raindrop-impressions, or organic markings), thickness and extent.

Relations to subjacent rocks.—Conformable; nature of the underlying series; unconformable; eroded surface deeply disintegrated; eroded surface of relatively fresh rock unglaciated; eroded surface relatively fresh rock glaciated.

The matrices of the various types of conglomerates have not been very fully described. According to Geikie the small particles of detritus are generally less well rounded than those of greater dimensions.[1] This is doubtless true of all water-laid deposits. The evidence collected appears to show that the matrices of marine conglomerates tend to consist of clean sands fairly well sorted and often cross-stratified. Willis states of beach deposits that the "sand is clean and characterized by marked and irregular cross-bedding."[2] Russell, referring to the incrustation of the grains in certain ferruginous deposits, remarks that if the débris had been deposited in the ocean and exposed to the action of waves and currents, the sands would have been more thoroughly assorted than we now find them, and also that the attrition produced by the waves under such circumstances would have scoured off the incrustation of ferric oxide.[3] Dutton, too, emphasizes the more thoroughly assorted condition of marine sediments as opposed to fluviatile deposits. Of the latter he states that material of all sorts is deposited everywhere, yet with a tendency to

[1] *Text-Book of Geology*, 4th ed., Vol. I, p. 162.

[2] *Journal of Geology*, Vol. I (1893), p. 487.

[3] U. S. Geological Survey, *Bulletin No. 52*, 1889, p. 45.

sorting.[1] Probably the littoral deposits of lakes would approach marine deposits in uniformity of size and arrangement of particles, but with the absence of tides it is doubtful if these characteristics would be in general so highly developed.

Estuarine deposits are seen to consist in the main of mixtures of sand and clay, not very well assorted, but relatively fine. The matrices of crush-conglomerates would doubtless present much diversity in the size and shape, but not in the material, of their particles. Probably glacial deposits display the greatest variation in the character of the finer fragments that constitute their matrices. Fluviatile deposits may often approach them in heterogeneity of material and arrangement, and in angularity of individual particles. One minute distinction may, however, be noticed. In the case of small fluviatile fragments, which are only slightly rounded, the attrition will probably be equally developed on all corners or edges. In the case of similar glacial fragments, as shown by the microscopic study of the Dwyka conglomerate, one edge or corner of a particle may be smoothed or rounded, while other corners or edges remain sharply angular.

The evidence thus far collected goes to show that the pebbles of marine and lacustrine conglomerates tend to be well sorted and well rounded, though they may be subangular in proximity to their sources. Shrubsole, noting the way in which pebbles on a beach slip over each other with the recession of each wave, remarks: "The pebbles become as a rule symmetrical and lose all traces of angularity."[2] Estuarine pebbles tend to be but imperfectly sorted and rounded, and fluviatile pebbles may show all stages from confused heaps to well-stratified beds and from well-rounded forms to almost complete angularity. The difference between marine and fluviatile pebbles is thus expressed by Dutton:

> Attrition [in the fluviatile conglomerates of the high plateaus] is not ordinarily extreme. In most cases it is enough to indicate that the fragments are really abraded, though with no great loss of substance. The stones of subaqueous conglomerates, on the contrary, are always much worn and rounded. Again, the sizes of the stones [in the fluviatile conglomerate] range from a fraction of a cubic inch to several cubic feet; in rare instances to more than a cubic yard.[3]

[1] *High Plateaus of Utah* (Washington, 1880), p. 220.

[2] *Quarterly Journal of the Geological Society*, Vol. LIX (1903), p. 315.

[3] *Loc cit.*, p. 224.

In crush-conglomerates the shapes and sizes are variable, depending on the character of the rocks crushed, and on the character and amount of the deforming force. No doubt the pebbles would often be distorted and contain fracture planes and tension cracks. Glacial pebbles are characterized by variety in composition, size, and shape. Their sizes and shapes may, however, be so successfully imitated by bowlders and pebbles of fluviatile origin that it is only when the fragments are seen to bear the characteristic glacial striae, or to be intimately associated with stones that are so marked, that their glacial nature can be regarded as established. Even here caution is needed; for in landslides or mud flows, or by the action of shore- or river-ice, striated pebbles may be produced, which closely resemble those developed by glacial action.

While the evidence shows that marine conglomerates are sometimes ferruginous, the trend of opinion seems to be that such rocks are not, as a rule, highly colored. According to Russell, observations show that lacustrine sediments are usually not red.[1] The evidence found with reference to the color of estuarine deposits is insufficient to make any general statement; they are, however, often considered to have a tendency toward a red color. Some of the fluviatile deposits studied are shown to have highly colored or purplish zones. Strahan, speaking of the characteristics of continental formations, says they have a common tendency to a red color.[2] Crush-conglomerates, being induced as secondary structures in rocks already formed, partake of whatever color the parent rock may have possessed. Glacial conglomerates, as a rule, appear not to be highly colored, though the Australian bowlder-beds are described as containing reddish-brown members. Red color is therefore not a distinctive characteristic of any particular type of conglomerate formation, but it may be said to be more common in the fluviatile and perhaps in the estuarine types than among the other kinds of conglomerate.

Marine formations have been found to possess, on the whole, the most uniform bedding; while glacial formations exhibit the least developed and perhaps the most irregular stratification. Lacustrine and estuarine formations tend to resemble those of marine origin,

[1] U. S. Geological Survey, *Bulletin No. 52*, 1889, p. 47.

[2] *Quarterly Journal of the Geological Society*, 1897, pp. 143, 144.

while fluviatile formations may be well stratified, or, on the other hand, may so closely simulate heterogeneous glacial accumulations as to make their origin uncertain: witness the discussion of the Midland Pebble Beds of the Old Red Sandstone. Cross-stratification and lenticular masses of coarser and finer material are common in all these types, but in the marine type the long axes of the lenses are more frequently parallel to the shore line—that is, to the original strike of the rocks; while in the case of fluviatile accumulations the long axes of the lenses are parallel to the courses of the stream threads by which they were deposited—that is, to the original dip of the rocks. All water-laid deposits appear to increase in thickness and coarseness toward their source of supply. Marine action, however, tends to produce sheets of relatively uniform thickness over wide areas, while fluviatile action tends to produce interwoven linear bundles of coarser and finer materials, which may attain great thickness in the aggregate over limited areas, but which thin out more rapidly than is the case with marine deposits. Other differences are cited by Strahan in his discussion of continental deposits. He states that the latter are not only unequal, but alternate with erosion, so that fragments of one bed are included as pebbles in another; that they rarely contain marine organisms or such strata as usually compose marine formations, but that drifted plant remains are not uncommon, and that such limestones as occur consist, when unaltered, of amorphous carbonate of lime and not of organic remains.[1] Current markings, sun-cracks, and foot-prints, or other impressions common on exposed mud-flats, are frequent in estuarine and probably in fluviatile or lacustrine deposits, but do not ordinarily occur in marine formations.

In crush-conglomerates no true bedding appears, and all traces of the original bedding may have been destroyed. The bedding of ice-laid deposits is very obscure, and that of fluvio-glacial deposits merges into that of true fluviatile deposits, so that little or no distinction can be drawn.

As regards the relations of conglomerates to subjacent rocks, the main fact brought out by the investigation is that those formations of any age, that have been proved to be glacial, have been found to rest upon striated rock surfaces. The possession of heterogeneous

[1] *Loc. cit.*

Type	Crush	Glacial
Matrix	Ctoclastic fragments.	Heterogeneous mass of finer and coarser material, compact, angular grains of minerals and rocks; some fresh feldspar; some grains partially rounded and partially angular.
Pebbles	ce and shape, angular to showing portions of limbs of folds; fracnes; tension cracks. tic fragments.	Generally local materials, but a considerable proportion from distant sources. Little, if any, assortment; all sizes up to masses of several tons. Pebbles faceted, rounded edges, snubbed ends, polished and striated surfaces, with striae generally parallel to long axis of stone, but often showing two or more directions.
Color	M parent rock.	Generally dark grayish with bluish and greenish tints, occasionally ferruginous.
Bedding	Sedding, all traces of bedding may have been 1.	Till and corresponding ancient formations, usually not bedded; sometimes obscure stratification, and layers when separated show glazed and striated surfaces; sometimes pockets, lenses, and beds of coarser and finer stratified material with cross-stratification included in the unstratified mass. Fluvio-glacial materials show all gradations from no stratification to well-marked fluviatile type. Marine glacial bowlder beds show well-marked stratification and alternation of coarser and finer beds.
Relations to Subjacent Rocks	Conformity by overulting or slickensiding.	Rests on striated, smoothed, and polished surfaces of older rocks or older portions of the same formation.

structure, irregular and striated pebbles, while furnishing strong evidence of glacial action, cannot be considered as conclusive proof, for such structures and forms may be produced in other ways. When, however, such forms are found to rest upon a smoothly polished and striated rock surface, the weight of evidence is so great that no other explanation can be accepted.

To summarize: Marine sediments exhibit, on the whole, the greatest uniformity of composition and the most orderly arrangement of materials, while glacial deposits display the opposite characteristics. Lacustrine, estuarine, and fluviatile accumulations attain intermediate degrees of uniformity. Each of the various types of conglomerate possesses features that are shared to some extent by other types. Thus there is no single feature which in itself distinguishes any particular kind of conglomerate. It is only when a number of features of one type are grouped and compared with a similar group of another type that definite distinctions can be made. Such a comparison is attempted in the accompanying tabular summary.

RESTORATION OF DIADECTES

E. C. CASE
University of Michigan, Ann Arbor, Mich.

In 1905 the writer published in the *Journal of Geology* (Vol. XIII, No. 2) a description and discussion of the genus *Diadectes* Cope, based on several specimens forming part of the collection of the University of Chicago, and especially upon specimen No. 1075. More prolonged study and the discovery of several additional specimens make it possible to attempt a restoration. It is unfortunate that the species to which this specimen belongs cannot be determined. The specific characterization of members of this genus has been made entirely upon the teeth, and in this specimen the jaws are so tightly closed that their form cannot be made out. The only parts of the restoration not based upon No. 1075 are the feet, the distal ends of the lower-limb bones, the exact form of the posterior lumbar ribs, and the number of the caudal vertebrae. The form and proportions of the lower-limb bones have been determined from other specimens, and the shortness of the tail has been verified. The general character and proportions of the feet are also known from other specimens, as is the exact shape of many of the bones composing them; it is probable that the feet are somewhat too small in the restoration.

The restoration is one-sixth natural size; the animal, it is thus seen, was not far from three feet, six inches in length. This is by no means the largest representative of the genus, since another specimen known to the writer is nearly one-third larger.

The skull is relatively large and clumsy, set closely on the heavy spinal column, with practically no neck. It is noticeable that the heavy lower jaws hang as low as the sternum, giving the animal a bodily habit strikingly like that of the Stegocephalia. The vertebral column is very heavy, and its vertebrae are closely interlocked. The ribs are broad and heavy in the thoracic region, and are found on all the presacral vertebrae, even the atlas. No abdominal ribs have been found in any specimen of the genus, nor of the related genus

Empedias, but it seems very probable that they were present, both because of the prone attitude of the animal, and of its probable ancestral position as regards the Chelonia. It will be of the utmost interest to determine the presence and form of the abdominal ribs, if there be such.

The limbs are remarkably stout and short, with prominent rugosities for the attachment of powerful muscles. The feet are less well known, but the form of the known carpal and tarsal bones, and the shape of the phalanges, indicate a loosely knit foot, relatively broad and clumsy. The general form of the carpal and tarsal bones seems to have been similar to that of the Pariotichidae and the Pelycosauria, though much less perfectly modeled. The terminal phalanges are short and semicircular, covered with strong rugosities (see *Journal of Geology*, Vol. XI, No. 4, Fig. 6, p. 400); it is evident that there were no powerful claws, as in the pelycosaurs, but rather broad and clumsy ones. The most remarkable feature of the skeleton is the presence of plates overlying the first five dorsal ribs. As shown in Fig. 2, the first of these is very small, the second one far larger, and the succeeding three relatively narrow and high. They overlie the ribs directly,

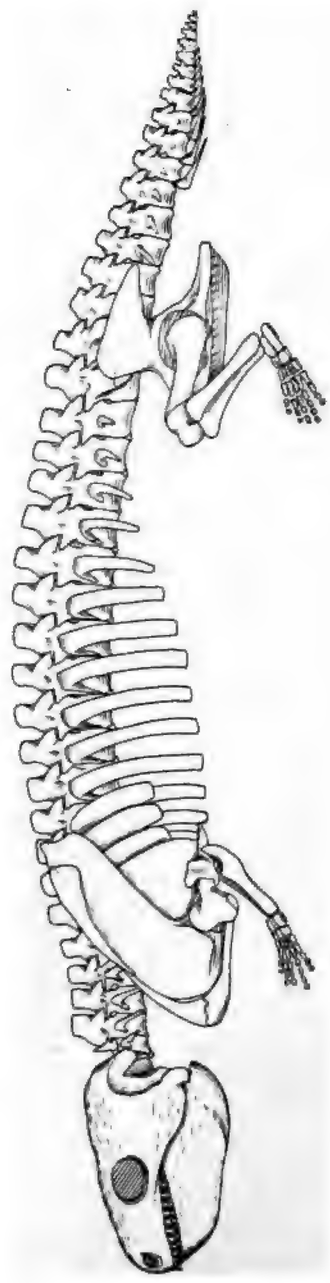


FIG. 1.—Restoration of *Diadectes*, sp., based on specimen No. 1075, University of Chicago collection. The feet are based on imperfect feet of other specimens. ×⅛.

and overlap each other from before backward. Two specimens show the presence of these plates in the position of the restoration, but there are no traces of others on the sides of the ribs or on the summits of the neural spines.

The position of the plates below the scapula is anomolous but there seems no escape from the conclusion that they are restored in the natural position; if the animal was very broad and low, grotesquely so, then the pectoral girdle might have touched only the outer ends of the ribs and the plates might have lain above the girdle; but the condition of the specimen forbids such a conclusion. The pectoral girdle is exceptionally well preserved and free from distortion, the bones are closely articulated and in their proper positions; the whole pectoral girdle has the form of a narrow U with the bottom forward. In fact the animal was distinctly narrow chested. There seems no possibility that crushing could have forced the plates into this position. This is perhaps one of the greatest arguments against the position of the Diadectids as ancestral to the turtles. Cope describes the pectoral girdle of *Otocoelus* and *Conodectes* as internal to the dermal plates which are however much larger proportionally than in the Diadectids.

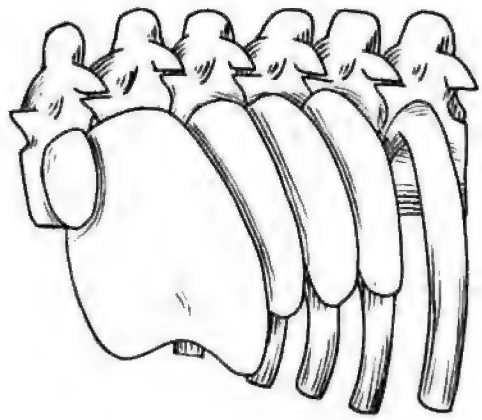


FIG. 2.—Six anterior dorsal vertebrae of *Diadectes*, sp., showing the form and position of the plates overlying the ribs. Specimen No. 1075, University of Chicago collection. $\times \frac{1}{3}$.

The assemblage of characters shown in the restoration seems to bear out the suggestion made in the previous paper (*loc. cit.*) that the Diadectids are perhaps the nearest to the turtles of the forms now known. The powerful head and jaws, with their numerous testudinate characters, the strong thoracic guard formed by the great scapula with its clavicle, cleithrum, and interclavicle; the short, powerful

limbs; the loosely knit splay feet, with their ill-developed terminal phalanges, all give an impression of a compact body lying close to the ground, and moving with a sprawling gait, much as in the turtles. The compactness of the body and the strong limb-bones led Cope to suggest that these animals were perhaps fossorial; but the character of the feet seems to preclude any such possibility. They must have been more like the great stegocephalians, but without their carnivorous habits—lowly, sluggish, inoffensive herbivorous reptiles, clad in an armor of plate to protect them from the fiercely carnivorous pelycosaurs.

DOME STRUCTURE IN CONGLOMERATE[1]

RALPH ARNOLD

CONTENTS

LOCATION AND COMPOSITION OF THE DOMES

On the flanks of Eagle Rock Valley, two miles west of Pasadena, Cal., are several dome-shaped structures developed in conglomerate. They resemble in a general way the granite domes of the Sierra Nevada, but are much smaller and also less isolated as regards the surrounding topography. The conglomerate is of lower Miocene age, is quite regularly bedded, somewhat tilted, and consists of sand pebbles and boulders of the granite, diorite, gabbro, gneiss, and other crystalline rocks which form the San Gabriel Mountains to the north. Some of the boulders are as much as 6 feet in diameter, although the average are not over 3 or 4 inches; some of the layers are little more than coarse pebbly sandstone.

EAGLE ROCK

The largest and most perfect example of a dome is found at the east end of the valley, and is called Eagle Rock. Fig. 1 is a view of Eagle Rock as seen from the southwest, and shows its position with respect to the surrounding topography. The "eagle" may also be seen on its 80-foot precipitous west face. The hills west and south of the rock are of conglomerate, similar to, except softer than, that composing the dome, and dipping in the same direction. The hills immediately to the north—to the left of it in this view—are of crys-

[1] Read before the Geological Society of America, December 28, 1906, and published by permission of the Director, U. S. Geological Survey.

talline rocks, and are separated from the conglomerate by a fault, the latter, however, having no apparent relation to the origin of the dome. The bedding of the conglomerate is plainly marked by the lines of protruding pebbles and cobbles on the south side of the rock.

FIG. 1.—View of Eagle Rock, a conglomerate dome, seen from the west, showing its relation to the surrounding topography: front elevation 80 feet.

The blocks immediately in front are fragments of the layer or shell, the remaining parts of which form the prominent overhanging V-shaped block. This layer was from six to eight feet through, and possibly more. A crack extends upward under the north arch of the overhanging block but none is present under the south arch, the block and adjacent dome face meeting in a solid concave junction. The

iron stains seen on the west face of the rock in this view, and in Fig. 3, emanate from the cracks under the scales.

A view of Eagle Rock from the south is shown in Fig. 2. This picture presents a profile of its west face, showing the solid joint between overhanging block and nearly perpendicular rock face; also the rough, pebble-covered south wall of the dome. The top of the rock conforms approximately to the dip of the conglomerate, and

FIG. 2.--Eagle Rock, viewed from the south, showing bedding in the conglomerate, and a profile of the west face.

is devoid of vegetation with the exception of a patch or two of moss and a few straggling shrubs.

The north side of the dome, shown in Fig. 3, is penetrated by two caves which have been formed by the weathering-out of the incoherent portions of the rock. These caves are the result of phenomena different from those resulting in the scales and dome surfaces. The walls of the caves are concave inward, somewhat softer than the exposed surfaces of the dome; the bottoms of the caves slope gently outward. Beneath the caves will be noticed several arches similar in a general way to the great arch. These are of various sizes as

regards length and thickness, and represent the lower edges of more or less well-developed scales. Small scales transverse to the larger ones are often developed across the lower portions of the latter, the line of parting always beginning at the interior surface of the larger scale and extending up into it toward its outer surface. An example of such a secondary scale is shown in Fig. 4, which is a profile of the north face of Eagle Rock. Many other scales, some of them from

Fig. 3.—Near view of Eagle Rock, from the north, showing caves, some smaller arches, and profile of the west face.

one to six inches thick, and some thinner, but most of them inconspicuous in the photograph, are developed over the steeply sloping faces of the rock. It is a very significant fact that the interior walls of the caves, which are practically dry at all times, are not scaling off; neither is the south face, nor the top of the dome.

OTHER EXAMPLES

At the western end of the Eagle Rock Valley are several prominent examples of dome structure in conglomerate similar to that composing

Eagle Rock. Some of these are little more than huge boulders, and one of them is only about ten feet in diameter. This last one, however, presents a very characteristic dome surface, with accompanying scales and arches on three sides, east, north, and west. In the vicinity of the small dome is the conglomerate exposure shown in Fig. 5.

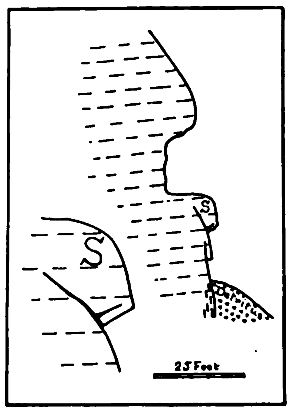


FIG. 4.—Profile of north face of Eagle Rock, with detail of scale at S, latter showing transverse crack in scale.

Taken as a whole it is but a small fraction of a complete dome, but it offers the best opportunity for detailed study of the phenomena of dome formation of any of the examples in this region. The view is looking north; the conglomerate dipping northeast. The surface bows over from a slope of 30° to one of approximately 60°. The overhanging block on the face of the dome is about four feet thick at its thickest point, and consists of hard, little-weathered conglomerate. The block thins toward the southeast (the right in the photograph), the crack under it narrowing proportionately at the same time.

In direct contrast to this hard sheet is a 3-foot zone of weathered rock shown in detail in Fig. 6, which was taken looking west into the crack extending under the outer shell on the left in Fig. 5. The hammer stands vertical, the handle resting on the hard surface of the new dome face, the head resting against the weathered zone, and the upper portion of the picture displaying the hard outer shell. The weathering process has resulted in the formation of a series of laminae (noticeable in the picture above the head of the hammer), from a small fraction of an inch to an inch in thickness extending approximately parallel to the dome surface. The planes separating the laminae pass through the conglomerate in most cases irrespective of the composition and hardness of the component parts of the rock, appearing to cut the hard granitic cobbles as readily as the softer arkose matrix. An exception to this is the exceedingly hard aplite boulder seen on the extreme left of the photograph. An idealized profile of the dome-face just described is shown in Fig. 7.

It is worthy of note that domes are so far known to occur only in plutonic rocks or in a clastic rock made up entirely of material of plutonic origin. This is true probably because the coincidence of texture and mineral constitution, essential to the peculiar type of weathering causing the scaling process, is confined to plutonic rocks.

SUMMARY OF OBSERVATIONS

Concerning the scaling process itself in the conglomerate the fol-

FIG. 5.—Dome surface in conglomerate at western end of Eagle Rock Valley, viewed from the south, showing crevice under large scale.

lowing observed facts and the deductions drawn from some of them may be given:

1. The scales are not found on slopes of less than 30° or 40°, thus showing that the process is influenced by gravity.

2. The scales are almost entirely absent from the exposed southern faces and other portions of the rock, which are kept dry or practically dry, most of the time, indicating that moisture is a necessary agent in the process. The paucity of the scales on the surfaces most exposed to the sun argues against change in temperature being responsible for their formation.

3. The cracks separating the scales from the dome-face always penetrate upward, never downward, and approximately parallel the outer surface of the scale.

4. The incipient cracks are closely followed by a zone of weathering which often shows thin lamination parallel to the crack, and which, crumbling away, produces a crevice. The intensity of the weathering which goes on in this zone is often evidenced by the iron and other stains which emanate from the cracks and run down the surface of the dome.

PREVIOUS THEORIES REGARDING THE ORIGIN OF DOMES

Two general theories have been advanced in explanation of such peculiar structure, all heretofore, however, based upon observations of the development of domes in granite. Gilbert[1] states these theories thus:

"According to one theory the separation of the granite into curved plates is an original structure, antedating the sculpture of the country and determining the peculiarities of form. According to the other theory the structure originated subsequently to the form, and was caused by some reaction from the surface."

Becker,[2] Branner,[3] Dana,[4] Geikie,[5] G. P. Merrill,[6] Shaler,[7] Turner,[8] Gilbert,[9] and Chamberlin and Salisbury[10] support the latter theory, while Le Conte,[11] Muir,[12] Whitney,[13] Bonney,[14] and some German writers[15] are in favor of the first.

[1] *Bull. Geol. Soc. Am.*, Vol. XV, 1904, pp. 29, 30.

[2] *U. S. Geological Survey*, Monograph 13, pp. 70–72, 1888; *Tenth Ann. Rept. U. S. Geol. Surv.*, 1890, p. 142; *Bull. Geol. Soc. Am.*, Vol. II, 1891, p. 69.

[3] *Bull. Geol. Soc. Am.*, Vol. VII, 1896, p. 281.

[4] *Manual of Geology*, 1895, p. 127.

[5] *Textbook of Geology*, 1893, p. 348.

[6] *Rocks, Rock-Weathering and Soils*, 1897, pp. 180–184.

[7] *Proc. Bost. Soc. Nat. Hist.*, Vol. XII, p. 289.

[8] *Proc. Cal. Acad. Sci.*, 3rd ser., *Geology*, Vol. I, p. 315.

[9] *Loc. cit.*, pp. 30–34.

[10] "Processes and Their Results," *Geology*, Vol. I, 1904, pp. 41–46.

[11] *Elements of Geology*, 4th ed., pp. 283, 284.

[12] *Proc. Am. Assn. Adv. Sci.*, Vol. XXIII, pp. 61, 62.

[13] "Geol. Surv. Calif.," *Geology*, Vol. I, pp. 371, 372.

[14] *Quart. Jour. Geol. Soc. London*, Vol. XXXII, 1876, p. 140

[15] Turner, H. W., *loc. cit.*, p. 313.

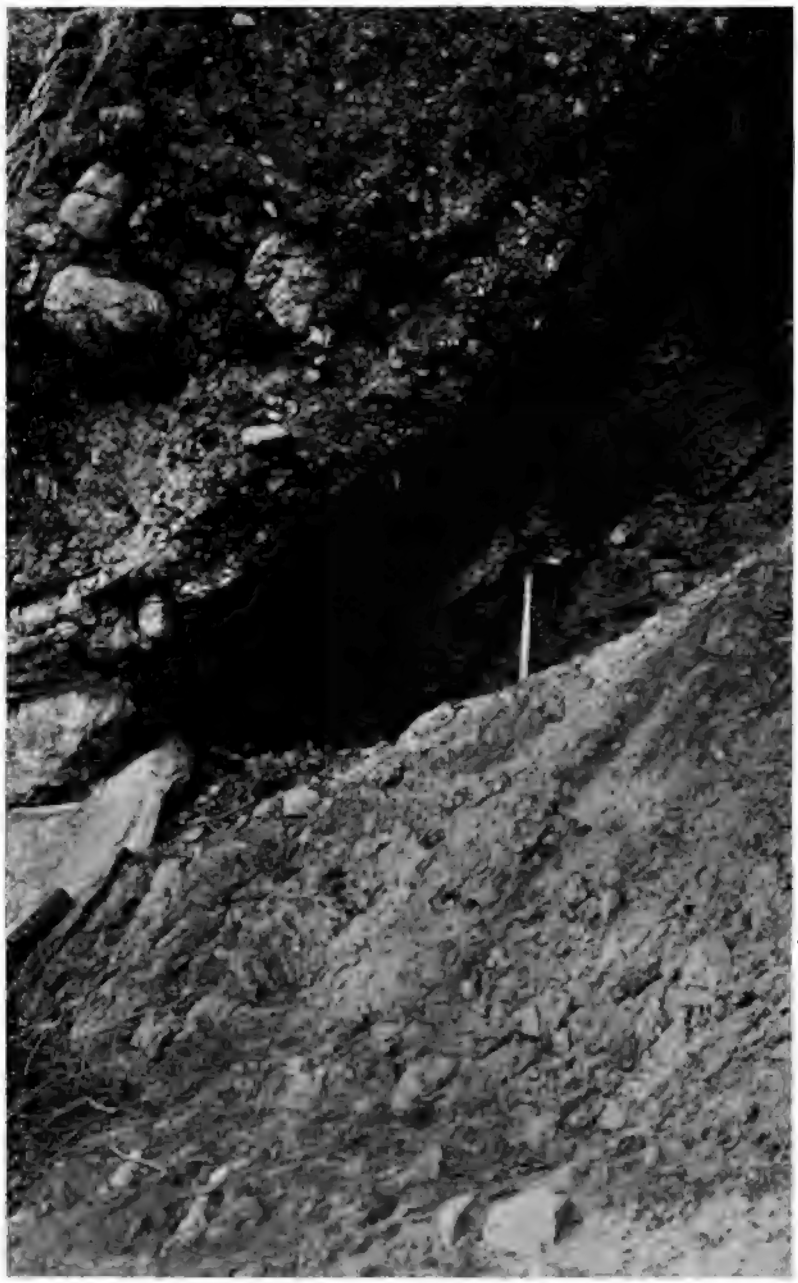


FIG. 6.—Detailed view of crevice shown in Fig. 5, looking west, showing lamination of the conglomerate in the weathered zone.

Those who support the theory of reaction from the surface differ as to the agent or agents which have brought about the result. Becker[1] believes the great granitic domes to be simply cases of exfoliation on a large scale, their regular curvature being due to the fact that, measured per unit volume, the surface exposed is in inverse ratio to the radius of curvature, so that the sharply curved surface weathers fastest. Furthermore he says:[2] "Weathering and abrasion proceed with a rapidity which increases with the surface exposed per unit volume. Hence these processes lead to minimum surfaces. Therefore, also, the mathematics of erosion is essentially identical with that of capillarity."

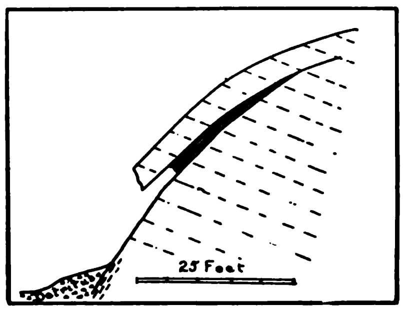


FIG. 7.—Section of dome at west end of Eagle Rock Valley, showing weathered zone below overhanging block.

Branner,[3] from observations in Brazil, expresses the opinion that the even annual and diurnal changes and the approximately even penetrations of these changes cause the rocks to exfoliate or to shell off in layers of even thickness like the coat of an onion. Merrill[4] attributes exfoliation largely to temperature changes, but considers the curved partings in the rock below the exfoliating surface as the result of torsional strains. Chamberlin and Salisbury[5] account for exfoliation on both a small and a large scale (including the dome structures of the Sierra Nevada) by great daily, rather than by great annual, changes in temperature causing expansion and contraction in the outer layers of the rock. They also consider the wedge work of ice effective in augmenting the scaling caused by expansion. This latter cause would necessarily be inoperative in that part of southern California in which Eagle Rock is located, for the temperature here seldom descends to 32° F.

[1] *Tenth Ann. Rept. U. S. Geol. Surv.*, 1890, p. 142.

[2] "Present Problems of Geophysics," *Science*, n. ser., Vol. XX, 1904, pp. 551, 552.

[3] *Loc. cit.*, p. 281.

[4] *Loc. cit.*, pp. 180–84.

[5] *Loc. cit.*, pp. 42–44.

Gilbert[1] suggests three processes, all of which, according to him, may be concerned in the formation of domes, viz.: (*a*) secular changes in temperature (he dismisses annual and diurnal changes because their influence penetrates but a small distance); (*b*) expansive force developed in weathering, and (*c*) dilation from unloading.

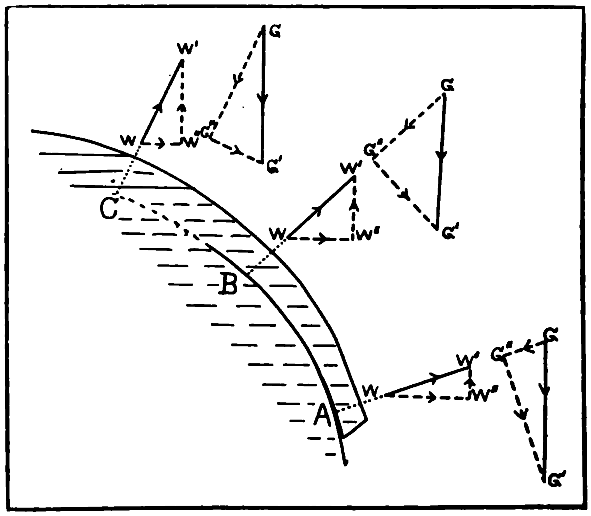


FIG. 8.—Graphic representation of some of the forces effective in dome formation. WW′=expansive force due to weathering, acting at A, B, and C.

GG′=weight of overhanging or loosened block effective at A, B, and C.

WW′−(GG″+cohesion and adhesion of conglomerate)=EF=effective force tending to formation of crack.

The component of EF acting in the direction WW″, and G″G′ tend to removal of loosened block; these two forces become less and less as the slope of the dome surface decreases, reaching the value zero at the point where the tangent to the surface is horizontal; where the tangent is vertical they have their maximum value of WW′ and GG′, respectively. The scaling process is, therefore, most effective on vertical faces, becoming less and less so as the faces approach the horizontal.

CONCLUSIONS REGARDING THE ORIGIN OF CONGLOMERATE DOMES

The conclusions reached by the writer, regarding the origin of the conglomerate domes just described, involve both of the two general theories previously given, and may be tentatively stated as follows:

In the first place they are locally hardened portions (gigantic concretions, if you please) of a practically homogeneous conglome-

[1] *Loc. cit.*, p. 32.

rate of plutonic rock material. After the ordinary process of erosion uncovers a sufficient surface of the indurated rock the dome structures are formed by a successive scaling-off of blocks, through the development of cracks approximately parallel to the steeply sloping surfaces. These cracks are probably due to expansive force developed by chemical reactions (weathering) produced largely by moisture, the moisture passing upward by capillarity through the incipient cracks caused by expansion, and thus advancing the process. The cracks originate in positions advantageous to the accumulation or retention of the moisture producing the weathering, such, for instance as that occupied by the detrital material at the base of the slope or in the angle between overhanging blocks and the new dome surface. The direction of the cracks is determined by the configuration of the rock surface, being approximately parallel to it, the departures from strict parallelism being of such a nature as to omit angles and other features of irregularity. This parallelism to the surface is due to the expansive force acting along lines of least resistance, which in this case are practically normal to the outer rock surface. The slope of the surface is the governing function in the removal of the scales because the components of gravity and of the expansive force tending to dislodge the separated scales is greater on steep slopes than on low, while the component of gravity tending to counteract the expansion due to weathering is correspondingly less on steep slopes, becoming greater as the angle of declivity lessens.

Fig. 8 illustrates graphically the two principal forces (expansive force due to weathering, and gravity) effective in dome formation. These forces are resolved into components at three different points on the dome surface, in order to make clear the last sentence in the preceding paragraph.

PRE-WISCONSIN DRIFT IN THE FINGER LAKE REGION OF NEW YORK

FRANK CARNEY

CONTENTS

INTRODUCTION

With old drift on Long Island,[1] in New Jersey,[2] and in northwestern Pennsylvania,[3] it is very likely that a line of old drift should connect these areas. If, however, these localities of old drift represent ice-work from separate dispersion centers, then the re-entrant

[1] J. B. Woodworth, *New York State Museum Bulletin 48* (1901), pp. 618–70; M. L. Fuller, *American Geologist*, Vol. XXXII (1903), pp. 308–12; A. C. Veatch, *Journal of Geology*, Vol. XI (1903), pp. 762–76.

[2] R. D. Salisbury, Geological Survey of New Jersey, *Annual Report for 1893*, pp. 73, etc.; Vol. V (1902), pp. 187–89; 751–82.

[3] F. Leverett, *Monograph XLI*, U. S. Geological Survey (1902), p. 228; L. H. Woolsey, *Beaver Folio*, No. 134 (Pennsylvania), U. S. Geological Survey (1905), p. 7.

angle not covered by this drift might include much of New York state; but this supposition is hardly in harmony with accepted facts concerning the centers of ice-dispersion. Theoretical consideration, therefore, leads to the conclusion that in the Finger Lake region of New York the late Wisconsin drift sheet covers at least the ice-erosion remnants of older drift. Students of glacial geology have already tentatively presumed earlier glaciation in this region.[1]

That there has not already been reported some observed evidence of pre-Wisconsin drift in the Finger Lake region is doubtless due to one of two causes: workers may have felt that such drift should be highly weathered; or that at this distance north of the ice-margin erosion was so vigorous as to have removed the earlier drift. In all probability ice-erosion has removed most of the weathered horizon of the old drift, mingling it so thoroughly with fresh débris that it is not easily identified. In walking over the fields of the lake country one notes the presence of small bowlders which are very much weathered, bowlders that remind him of the general condition of stones in the areas of old drift; this is the most pertinent suggestion of the earlier glaciation of this region.

PRE-WISCONSIN DRIFT IN GENERAL

The older drift sheets have been studied more thoroughly in the Mississippi basin than elsewhere; their chronological sequence is generally established on the degree of weathering exhibited. In the case of the Sub-Aftonian[2] and the Iowan,[3] the lithological content is made a discriminating feature; the absence of water-laid material is a feature usually emphasized in describing the Kansan drift,[4] whereas the blue or blue-gray color of the unweathered Illinoian is pointed out.[5] Where the formations of different sheets of drift are superposed, the distinctions may be more accurately recorded; but good sections of this imbrication are rare. Some contact sections, all from

[1] R. S. Tarr, *Journal of Geology*, Vol. XIV (1906), pp. 18, 19; *Bulletin of the Geological Society of America*, Vol. XVI (1905), p. 217; H. L. Fairchild, *ibid.*, p. 66.

[2] W. J. McGee, U. S. Geological Survey, *Eleventh Annual Report* (1891), p. 497.

[3] Chamberlin and Salisbury, *Geology*, Vol. III (1906), p. 384.

[4] *Ibid.*, p. 389.

[5] F. Leverett, *Monograph XXXVIII*, U. S. Geological Survey (1899), p. 28; *Monograph XLI* (1902), p. 272.

the Mississippi valley, are shown in Chamberlin and Salisbury, *Geology*, Vol. III, pp. 385–88.

Descriptions of old drift in western Pennsylvania and in New Jersey are perhaps more pertinent to the New York area. The old deposits in Pennsylvania, described by Leverett, are very stony, the pebbles usually showing water action; the bowlders are small and mostly of local origin; only a small amount of clay is present; there is

FIG. 1.—Southern portion of Bluff Point viewed from the east. The break or terrace in the frontal slope is a cusp which apparently correlates with Fairchild's Wayne overflow stage of glacial lake Hammondsport.

slight evidence of bedding; the highly weathered condition of the drift, and the great amount of erosion it has suffered, are its conspicuous characteristics.[1]

The earlier drift in New Jersey is thus described: "The outer and older drift is deeply weathered from top to bottom, even where it has a thickness of thirty feet, the greatest thickness it is known to possess. Its stones, so far as they are of decomposable rock, are decayed.

[1] *Loc. cit.*, pp. 228, 229, 235.

From it most of the calcareous matter has been leached."[1] "The constitution of the drift is, in a general way, comparable to that of the younger drift. It contains materials of all grades, from huge bowlders to fine clay." "Limestone is rarely present. When the drift occurs in quantity, glaciated stones are by no means rare."[2] "It generally lacks all indication of structure, though foliation is to be seen in some of the deeper exposures." "In its constitution, and in the relations of its constituents, the drift corresponds with till."[3]

It should be noted, however, that Salisbury does not find the extramorainic drift in New Jersey uniform in the stage of weathering attained;[4] for this reason he suggests that, while most of it probably corresponds to the Kansan, it is possible that a younger pre-Wisconsin drift may be represented.[5]

Geographical factor.—The above descriptions of drifts pertain to deposits more or less distant from central New York. The diversity in the stratigraphy and topography of northern North America introduces other considerations that may render these descriptions only partly applicable to other regions. Similarity of glacial deposits elsewhere may result only from identity (*a*) in the stratigraphical terranes which furnished the débris; (*b*) in the period and conditions of weathering to which the débris was later exposed; (*c*) in the successions of ice-invasions; and (*d*) in the distance of the sections being compared from the termination of the particular sheet in question. It is evident, therefore, that in New England, New York, Pennsylvania, and New Jersey specific drift-sheets may have somewhat different features than have been reported by investigators elsewhere.

TOPOGRAPHIC CONTROL OF THE EROSION AND DEPOSITION OF DRIFT

In general.—It is probable that the main dissection lines of the Finger Lake area even before the earliest glaciation were north-south valleys; the troughs of the present lakes, their tributaries, primary, secondary, and lesser, had developed a variety of transverse valleys. So in whatever direction the ice-mass moved there must have been localities, of rather limited extent, where ice-erosion was less active;

[1] R. D. Salisbury, *Glacial Geology*, Geological Survey of New Jersey, Vol. V (1902), p. 174.

[2] *Ibid.*, p. 188. [3] *Ibid.*, p. 757. [4] *Ibid.*, p. 769. [5] *Ibid.*, p. 782.

also localities where the deposition of ice-débris was more pronounced. The combined effects of glacial erosion by the different invasions has not removed all the residual soil, the regolith of preglacial weathering.[1] Nor would a succeeding ice-sheet carry off all the drift deposited by a preceding invasion. Therefore it remains to inquire into the conditions most favorable to the deposition, and least favorable to the ice-erosion of former drift-sheets.

FIG. 2.—An east-west section showing contact of the two drifts as exposed south of Dunning's Landing. The wavy, irregular line marks the upper surface of the blue till.

Deposition of drift.—Aside from the ground moraine, the thickness and irregularity of which attest the heterogeneously distributed load which is being carried by the retreating ice, the localized deposits of débris represent in the first place a reaction of climatic factors that cannot be specifically determined; and, in the second place, the

[1] H. L. Fairchild, ***Bulletin of the Geological Society of America***, Vol. XVI (1905), pp. 53–55; R. S. Tarr, ***American Geologist***, Vol. XXXIII (1904), p. 287, and F. Carney. The writer's unpublished notes on the Moravia (N. Y.) quadrangle afford further proof of the presence of preglacial weathered products in place.

influence of topography upon the detailed outline of the ice-front. Climatic control evidently occasioned the pulsations of halt and retreat marked by the irregularly spaced belts of thickened drift; while the distribution of drift within the belts themselves is due both to local topography and to the topography of the areas passed over, in so far as these areas have contributed to the load of the ice. Furthermore, the broader outlines of these irregularly spaced belts reflect the reaction of the larger topographic features and the general direction of ice-movement from the dispersion centers; in consequence of this we have the moraines of ice-lobes. It follows, then, that no satisfactory control can at present be announced for the spacing of these belts.

Nevertheless, the influence of topography upon the detailed expression of the drift within the belt admits of closer definition. We would refer particularly to the following three conditions: (1) In a uniformly level area the ice-front would be without pronounced re-entrant angles; the drift would have a correspondingly even front, while it might have a very irregular surface. This type of topography is apt also to impose its characteristics upon the drift itself, as may be seen in the prairie regions. (2) In a section where the major valleys approach a position transverse to the general direction of ice-movement, the drift is found massed in these valleys, especially on their iceward sides; while in the tributaries of these major valleys are moraine loops or dams. (3) If, however, the chief valleys approach a position parallel to the general direction of ice-movement, we find in them lateral moraines[1] blending into loops of drift in the bottoms of the valleys; while the secondary valleys may be partially clogged or buried with drift.

Erosion of drift.—With this distribution of drift there must have been differential erosional effects produced by a second invasion of ice. Rather slight modifications would be effected under condition (1). The work of another ice-sheet passing over such an area is compressive quite as much as erosive; the more evenly the original drift is distributed, the less obstruction it offers to the progress of later ice; whereas the weight of the overriding ice tends to compact this drift.

[1] R. S. Tarr, *Bulletin of the Geological Society of America*, Vol. XVI, pp. 218, 219.

During the interval of deglaciation, stream-channeling, in the featureless topography of condition (1), proceeded slowly, since, to some extent at least, the streams were consequent. But with a larger lapse of time between the periods of glaciation this surface may have attained the relief of mature dissection, when it would present to the ice of the next invasion an opportunity for more effective corrasive work.

Each succeeding invasion would remove less of the previously

FIG. 3.—Contact of the two drifts at Crosby. The broken line marks the upper surface of the compact blue till.

deposited drift; it seems very probable that the resultant of several glacial invasions of such featureless topography is somewhat aggradational. And the final form given this drift depends upon the width and spacing of the moraine belts, if the ice were subject to varying relations of feeding and melting; or upon the thickness of drift deposited in an extensive sheet in case the feeding and melting factors were about balanced, the melting being slightly the stronger of the two.

That the resulting forms due to the aggradational action of an ice-sheet overriding these two types of drift arrangement would not be identical seems reasonable.

The drift as described under condition (2) would suffer much less from a second invasion. The deposits in the major valleys—i. e., the valleys transverse to the direction in which the ice is moving—would be somewhat protected from erosion; the weight of the overriding ice would tend to indurate this drift. But the drift in valleys tributary to these, since they trend more in unison with the moving ice, must suffer much more from erosion. When such accumulations are rather thick, it is probable that a drumlinoid form is the resultant of degradation by a second invasion of ice, particularly in these tributary valleys.

The most marked erosional effects, however, are observed in the old drift as distributed under condition (3). These valleys accord with the direction of ice-movement; if they open toward the approaching ice, greater obstruction is offered to its progress, hence greater erosion results; if they lead away from the feeding ice, the disturbance of the adjacent material may not be so marked. In the former case—i. e., the northward flaring valleys—the older drift, if not eroded, is apt to be deeply buried because of the intense aggradational work of the valley lobes which characterized the margin of the waning ice-sheet. In the latter case the ice-erosion is less effective; the augmented ice-front drainage has degraded, shifted, or covered with later outwash the earlier deposits. The application of this principle probably varies inversely with the size or width of the valleys.

But the old drift in the minor valleys of condition (3) has suffered less from ice-erosion. The stage of development of these minor valleys, and their degree of transverseness to the moving ice, are important factors in controlling the extent of ice-erosion in them.

Furthermore, under all these conditions we should find more old drift preserved in areas where during either pre- or inter-glacial time the drainage has suffered rejuvenation. The chances of such old drift being later revealed is greater in the transverse drainage lines of condition (3).

INHERENT CHARACTERISTICS OF OLD DRIFT THUS PRESERVED

Compactness.—The obvious resistance which this old drift offers to stream- or wave-cutting is its most characteristic feature. The pressure of the overriding ice-sheet has not only rendered such drift very compact, but there should be seen, particularly where the original deposits were fine in texture, a foliation due to the pressure. Lamination also might be contemporaneous with the formation of the

FIG. 4.—The horizon of the Wisconsin drift is fairly well defined by the vegetation; the steep bare slope consists of very compact bluish till.

deposits, but in any event it would be induced by great pressure. The effect of the superincumbent weight of a second ice-sheet should be noted, where the drift has been dissected into rather vertical cliffs, in the tendency of the pebbles and bowlders to overhang.

Color.—In the region under discussion ice-erosion has had, in general, favorable conditions for effectiveness. The highly weathered zone of an earlier drift-sheet would be most disturbed or eroded by

another invasion of ice, except in the case where ice-erosion had fallen short of the unweathered zone. The part of this earlier sheet remaining should have its original color, or at least the color which it had just previous to being overridden. Its present color need not necessarily be fresh or untarnished, but there is strong presumptive evidence that no color alteration has occurred since the retreat of the Wisconsin ice which furnished the débris for a protective burial of this older drift.

TOPOGRAPHY OF THE FINGER LAKE REGION

General statement.—The wide, prevailingly mature, lake-bearing valleys of central New York have received critical attention from workers in many lines of geology. Less attention, however, has been given to the more mature defunct valleys generally transverse to these. It is the unusual parallelism of the former, and their marked scenic beauty resulting from the variously interrupted drainage history, that impel the comment of even the untrained observer. These long valleys opening to the north were occupied during the waning stage of the ice-sheet by valley glaciers[1] or by valley lobes which were relatively broad—a condition due to the iceward slope of the valleys.

Topography favors both ice-erosion and ice-stream aggradation.—These conspicuous valleys, digital-like in arrangement, because of their general north-south trend, molded the basal ice of the deploying sheet into forms that expedited erosion. Furthermore, the fact that these valleys sloped toward the overriding wedges of ice facilitated the acquiring of a load which in turn augmented the erosive power of the ice up to the time when the amount of this load became so great that the basal ice lost in velocity; it then did little degradational work. In consequence of this differential erosion we find that approximately the southern thirds of these valleys are zones of ice-aggradation. Therefore Professor Tarr's 900-foot-contour upper limit of most active erosion[2] defines a plain which dips into the Allegheny Plateau. The present attitude of this plain of erosion embodies some post-glacial deformation due to warping; but, neglecting the effects of

[1] H. L. Fairchild, *American Journal of Science*, Vol. VII (1899), pp. 252, 253.

[2] *Popular Science Monthly*, Vol. LXVIII (1906), p. 389.

this warping,[1] it is not likely that the plane would define a surface even parallel to its original attitude. Concerning the relation which this part of our continent bore to sea-level while the Wisconsin ice-sheet was active, we have insufficient data to warrant any but very general conclusions.

It is evident, then, that so far as the north-south valleys are concerned, exposures of the old drift are more apt to be found in a belt skirting the zone of heavy drift in the southern parts of the valleys; northward from this hypothetical belt erosion may have been very active, tending to remove the earlier deposits; southward, aggraded glacial rubbish has probably covered these deposits.

Few of the quite mature transverse valleys belonging to an interrupted but well-developed drainage cycle, above alluded to, have been described.[2] The more nearly transverse to ice-movement such valleys lie, the less ice-erosion they are subject to. Subsequent invasions of ice presumably have not removed much of the residual rock waste that escaped the earliest glaciation; nor would an earlier deposit of drift suffer great erosion. Consequently, valleys of this type are best fitted for the preservation of pre-Wisconsin drift. In the area covered especially by this paper two segments of such valleys, one extending eastward from the vicinity of Branchport (Penn Yan Quadrangle), the other extending westward from Dresden (Ovid and Penn Yan Quadrangles), have been studied.

LOCATION AND DESCRIPTION OF THE PRE-WISCONSIN DRIFT IN QUESTION

First indication of such drift.—In the area from Skaneateles to Keuka Lake the writer has often noted the highly weathered condition of smaller bowlders both on the surface and in cuts in the drift. Later acquaintance with the older drift in Ohio has led him to give further attention to this observation. These scattered, rather rotten crystallines may or may not suggest drift of different ages.

[1] G. K. Gilbert, U. S. Geological Survey, *Eighteenth Annual Report* (1896–97), pp. 603–6; H. L. Fairchild, *Bulletin of the Geological Society of America*, Vol. X (1899), pp. 66–68.

[2] R. S. Tarr, *American Geologist*, Vol. XXXIII (1904), pp. 271–91; F. Carney, *Journal of Geography*, Vol. II (1903), pp. 115–24.

It is not likely that the first or even the second ice-invasion removed all the residual products of preglacial weathering. This much weathered material would constitute a larger part of the first than of any later drift-sheet. And from the fact that residual decay is noted beneath the Wisconsin drift[1] it follows that some preglacial weathered products have withstood several periods of ice-erosion.

Western slope of Bluff Point.—This elongated ridge, drumlin-like in outline and slopes, peninsula-like in reference to the arms of the lake,[2] rises about 715 feet above the level of Keuka Lake. Its longer axis is meridional (Fig. 1.). The striae below the 1,100-foot contour measure S. 65°–28° W. So on the western slope of the bluff the work of the ice was dragging and plucking rather than abrading. But if these striae represent only the final ice-motion in the area, then the work of the glacier may have been more vigorous at an earlier stage. In any case, the striae indicate that this slope was leeward at least part of the time, hence the subdued erosion.

In the veneer of drift we note a conspicuous number of very weathered stones. These constituents in many instances are rotten, going to pieces under a blow of the hammer; others show in cross-section a surface altered zone, one-quarter to one-half inch wide. Even the pitted quartzite bowlders are not rare.

Eastern slope of Bluff Point.—On this opposite slope of the bluff a roadway leading northward from Dunning's Landing makes an exposure of highly weathered material just north of William T. Morris' cottage. This is the only section which suggests a concentration of rather uniformly altered drift constituents; neither the location nor the weathered condition of this exposure necessarily implies old drift.

About one-half mile south of Dunning's a recent stream channel reveals the contact of two distinct types of drift. The upper horizon is the familiar Wisconsin which here overlies a semi-indurated bluish till. This latter is fresh in comparison with the overlying Wisconsin which at this point is about 6 feet thick (Fig. 2.).

[1] H. L. Fairchild, *Bulletin of the Geological Society of America*, Vol. XVI (1905), pp. 64,65; R. S. Tarr, *American Geologist*, Vol. XXXIII (1904), p. 286.

[2] James Hall, "Geology of the Fourth District," *Natural History of New York*, Part IV (1843), p. 459.

Northward along this slope a similar arrangement of drifts was noted in three places.

On these steep slopes heavy rains and spring thaws open new channels cutting 10 feet to 15 feet in a few seasons. The Wisconsin drift is easily channeled; the other resists erosion more effectively. After a few seasons, however, the surface horizon weathers and covers the blue till formerly exposed.

As explained above, the direction of this valley is more nearly accordant with the direction of ice-movement; the older drift here was exposed, therefore, to more vigorous erosion. The portion of this old drift which has survived ice-erosion is the lower, unweathered parts. Thus the old drift is commonly fresher than the new.

The North Crosby exposure.—On the opposite shore of the lake, a few rods up the hill from the North Crosby Landing, a recent stream course discloses a hard bluish till, which shows no evidence of structure, overlain by Wisconsin drift. This channel in places is 15 feet deep; the maximum showing of the basal drift is about 4½ feet where it forms the bed of the cut, but it is not constant, the Wisconsin sometimes forming the entire cross-section of the cut. The hardness of the blue till here is evident from the overhanging of the bowlders (Fig. 3), which may be two-thirds disclosed before dropping from the face of the cut. We have not seen in this material bowlders more than a foot in diameter. The sharp angle of slope which this till maintains in comparison with that of the Wisconsin above is evidence also of the compressive force to which it has been subject.

Mixed exposures.—About a mile southeast of Branchport, near the point where the old valley joins the Branchport arm of the lake, a creek trenches the recent drift, which here contains scattered masses of blue till. We noted one area at the foot of the channel wall which may be in place. The Wisconsin drift here alluded to appears to be from a lateral tongue of ice which fed into the valley, thus disturbing the older deposits.

Another area where old drift is incorporated with the new is at the end of Bluff Point (Fig. 1). Here is a quantity of débris, largely local, dragged around the slope of the bluff.

Keuka Lake Outlet exposure.—The most pronounced section of the bluish till may be seen along the outlet of the lake. A typical expo-

sure is skirted by the highway and is in sight of the New York Central Railroad at Keuka Mills. Here the superjacent Wisconsin is the thinner, measuring a little less than 18 feet, while the bluish till measures nearly 30 feet. The ease with which the former weathers is demonstrated by the low angle of slope, and by the covering of vegetation; the older drift has a steep slope and no vegetation (Fig. 4), and shows very slight evidence of structure.

The outlet of Keuka Lake drops 265 feet in its course of scarcely 7 miles to Seneca Lake; it consists of a rock-bound gorge alternating with amphitheater expansions, in which one or both of the rock walls are absent where the present course crosses or enters a former more mature valley. The older drift is noted particularly in these amphitheaters of the present channel. It is probable, therefore, that the Keuka basin was tributary to the Seneca basin long before the period of bluish-till glaciation.

This same relationship of drifts is noted in the erosion channels of streams tributary to the Keuka Lake Outlet. Along the lateral from the south coming in at Milo Mills, the older drift, where not very coarse, shows a tendency to lamination, the result apparently of excessive pressure. We have noted the same condition in other localities of this region.

The most persistent expression of this bluish drift is found in the Keuka Outlet valley, which is transverse to the direction of ice-movement. The valley is very mature. Naturally the Wisconsin ice-sheet did less corrasive work here than in the arms of Keuka Lake.

Erosion and color.—Furthermore, the line of contact of the two drifts in the exposure about Dunning's and about North Crosby gives a suggestion as to the manner and amount of the erosion. The former contact is about 65 feet above lake-level; the latter, about 90 feet. In east-west cross-section the contact line is a series of sags and swells, or anticlines and synclines, presumably parallel to the direction of ice-progress, indicating its tendency to groove or plow the subjacent surface.

The color of this old drift is strikingly blue in contrast with the adjacent yellowish Wisconsin deposits, and the color persists even in the detached masses that are seen in exposures of the recent drift. It apparently is not the result of post-Wisconsin alteration; the till

has been too much protected for that, and its compactness argues against infiltering waters as the agent. The bluishness covers the bowlders and is constant in the matrix. Evidently the color antedates its erosion and burial by Wisconsin ice.

AGE OF THIS DRIFT

The evidence presented in this paper does not warrant an opinion as to the particular pre-Wisconsin epoch of glaciation with which this drift correlates. Critical study should be given a wider area southward to the outermost moraine of the Wisconsin drift; the numerous exposures noted in the limited territory already examined suggests that other superposed sections nearer the margin may show the older drift in a weathered condition.

The freshness of the subjacent bluish till about Keuka Lake does not suggest its correlation with the highly weathered till in New Jersey described by Salisbury. Nevertheless, this feature does not preclude identity of epochs, since the latter drift, which was never covered by a later till-sheet, has been subject to agents of disintegration during a period that has sufficed for the development of a well-advanced drainage system, the major streams having attained "levels more than 100 feet below the levels of the lowest summits on which the drift occurs."[1]

SUMMARY

This old drift, where now exposed, with one doubtful exception, is fresh in appearance; is very compact in structure, sometimes foliated; its bowlders preserve striae; its upper surface shows erosion, presumably somewhat beyond the removal of the weathered horizon which may be the source of some of the rather rotten crystallines now mingled with the recent drift.[2]

[1] R. D. Salisbury, *loc cit*, p. 759.

[2] The writer has just noted Gilbert's paper, "Bowlder-Pavement at Wilson, N. Y." (this *Journal*, Vol. VI [1898], pp. 771–75). The pertinent feature of this paper is the recognition of the possibility of two till-sheets, and of the certainty of "an epoch of local till-erosion by a glacier. The epoch may be a mere episode interrupting a period of till deposition by the same glacier, or it may be a part of a stage of readvance following a long interglacial period" (p. 774).

THE GLENEYRIE FORMATION AND ITS BEARING ON THE AGE OF THE FOUNTAIN FORMATION IN THE MANITOU REGION, COLORADO

GEORGE I. FINLAY
Colorado Springs, Colo.

The Paleozoic section to the east of Pike's Peak, Colorado, in the Manitou region is composed of four members, as follows: (1) a basal Cambrian sandstone; (2) a limestone series, the lower half of which is Ordovician (the age of the upper half is still in doubt); (3) a fossil-bearing sandstone of Pennsylvanian age; and (4) the Fountain formation, arkose sandstones, grits and conglomerates, the lower members of which are almost certainly of Pennsylvanian age, while the upper members may in the end be definitely correlated with the Permian and Triassic. The purpose of the writer in the present paper is to describe the sandstone member, (3) in the series as given above. It has not previously been described. It contains the only identifiable plant remains of Pennsylvanian age which have been found thus far in the Rocky Mountain region. These fossils make possible its safe correlation with the Upper Carboniferous of the East. The Fountain beds appearing in the section next above cannot, therefore, be older than the Pennsylvanian, and the occurrence in them of brachiopods which have been recently found points to their being of Pennsylvanian age.

Our knowledge of the Paleozoic section in the Manitou region warrants us in making the following statement with a large measure of confidence as to its correctness. Overlying the basal granite, which with its included schist and gneiss represents the Archean and Algonkian, there are found 50 feet of upper Cambrian sandstones. The lowest member of the Cambrian is an 11-foot band of white, fine-grained quartz feldspar sandstone. The succeeding layers going upward are stained by iron a deep red-brown, and they show irregular green markings due to the presence of glauconite. It is the upper Cambrian which is represented. The amount of lime increases

as one goes up in the series, until after 50 feet have been passed a gradual transition brings in thinly bedded limestones of Ordovician age, known as the Manitou formation. The line of demarkation between the Cambrian and the Ordovician in Manitou or Williams Canyon may be drawn at the "Narrows" just below the 18-inch band of hard, red, porous limestone which contains *Dalmanella testudinaria*. The beds up to this point are lithologically similar to the sandstones and limestones at the base of the section to the north along Deadman's Creek described by W. T. Lee,[1] and the correlation is justified by a comparison of the brachiopod faunas of the two regions. Near Canyon City, Colo., where cherty layers of the Manitou limestone rest directly on the granite, the Cambrian is wanting.

Above the Cambrian in the Manitou or Williams Canyon section 266 feet of limestones (including the Ordovician or Manitou limestones) were measured. A marked unconformity appears at the top of the series. The limestones at the base of the Ordovician are thinly bedded. Higher up the single layers are each one or more feet in thickness. Many of them carry chert inclusions. The prevailing colors are gray, bluish gray, and buff. A few layers near the top show deep red. The limestones are rarely free from magnesia, but a heavy band near the top is nearly pure lime carbonate.

The Silurian and Devonian are not known in the section, nor anywhere along the Front Range in Colorado. The Harding sandstone and the Fremont limestone of Ordovician age, so well represented near Canyon City, are not found in the Manitou region. To the north along Glen Eyrie Creek, three miles from Manitou, the limestone series is 311 feet thick.[2] Here Carboniferous fossils have been obtained from the upper beds by Dr. A. W. Grabau. It seems probable that at this point the equivalent of the Millsap, as suggested by Dr. G. H. Girty, is present, although the rock is not lithologically similar to the Millsap of the type locality in Garden Park, described by Dr. Whitman Cross. In the Manitou Canyon section there is no sign of an unconformity to mark Silurian and Devonian time until the top is reached. Fossils of Ordovician age occur at

[1] *American Geologist*, Vol. XXIX (1902), p. 96.

[2] See reference to Peale's section in *Professional Paper 16*, U. S. Geological Survey, p. 153.

many points in the lower 118 feet, but the upper 148 feet are not fossiliferous. It may well be that the Millsap has no equivalent in the section at this point.

Resting on the limestone, and separated from it by an erosional unconformity, are 40 feet of gray and buff, finely laminated sandstones, made up almost entirely of quartz grains, with thin bands of black shale near the bottom of the series. This formation is below the unconformity at the base of the Fountain. Typical exposures are met along the stream-bed in Quarry Canyon, a mile to the northeast of Manitou, where the upper contact with the Fountain is exposed. The basal contact with the highest brecciated limestones of the Manitou Canyon section may be seen on the right hand just at the entrance to Manitou Canyon. Small fragments of the limestone occur in the lowest beds of the sandstone, which rest on an uneven limestone floor. Southward from this point the formation is covered by overlap of the Fountain. It may be traced northward as far as Glen Eyrie Creek, where it is well exposed, although the Fountain comes down to the basal granite a short distance beyond, to the north. The sandstone formation in question is therefore of no great thickness, and its outcrop, an eighth of a mile or less in width and but three miles long, is of small extent. It possesses considerable interest, however, because of the fossil plants which are found in the shaly layers irregularly distributed through it. A collection of these fossils was made and forwarded to Dr. David White, of the United States Geological Survey. *Lepidodendron obovatum* and *Lepidodendron aculeatum* were identified by him. Dr. White has pointed out to the writer that these species indicate a horizon equivalent to the Pottsville of Pennsylvania. These plant remains are the only ones of Pennsylvanian age recorded up to the present time from the Rocky Mountain region. The shales which contain them are bands four feet and less in thickness, black from contained carbonaceous matter and traces of coal. They occur near the base of the formation, are at times lens-shaped, and quickly thin away. They indicate swamp conditions near the level of the sea. Lepidodendron markings have also been found in the sandstones. Concretionary markings are common in certain layers. The formation has not up to the present time received a name. It is proposed to call it the Gleneyrie

formation, making use of the name of the locality in which the best exposures are met. The Gleneyrie sandstone is a strong rock to resist weathering, and the weaker overlying Fountain grits have been stripped back down the dip for some distance from their outcropping edge.

The Fountain formation next above in the series, resting on the Gleneyrie sandstone and separated from it by an unconformity with overlap, has a thickness of over a thousand feet. The formation is made up of arkose sandstones, grits and conglomerates, red, vermilion, maroon, and occasionally white. Dr. Whitman Cross, who first used the name in the Pike's Peak folio, assigned the Fountain beds to the Carboniferous. It is clear that in the Manitou region, since they overlie the Gleneyrie sandstone, they are not earlier than the Pennsylvanian. Fossils from the Fountain are extremely rare, and only two genera, brachiopods, have been found in the Manitou region. They occur 200 feet above the base of the formation in a three-foot layer of red, fine-grained, shaly sandstone. Good exposures are met above the stone house in Quarry Canyon. Here shells of Orbiculoidea are not hard to find. Dr. G. H. Girty has kindly examined the specimens and referred them tentatively to *Orbiculoidea manhattanensis*. With them a single productoid shell, resembling *Marginifera ingrata*, has been collected, but the specimen is not sufficiently good for accurate determination. *Orbiculoidea Manhattanensis* has a wider range than the Carboniferous, but its occurrence at this horizon points strongly to the Pennsylvanian age of the Fountain beds near Manitou. The "Saurian" limestone conglomerate of Triassic age, so well developed in the San Juan Mountains of southwestern Colorado, is not known along the Front Range. For the final proofs as to whether any of the upper layers of the Fountain are to be referred to the Permian or to the Triassic we must await the results of such studies as Dr. Williston has been conducting in the Canyon City field.

THE HAMILTON IN OHIO[1]

CLINTON R. STAUFFER
Ohio State University

At the beginning of the deposition of the Devonian formations belonging to the upper part of the Ulsterian and early Erian series, much of Ohio lay beneath a great inland sea. The island caused by the Cincinnati geanticline, and covering parts of Ohio, Indiana, and Kentucky, according to Ulrich and Schuchert,[2] probably became connected with the mainland to the southeast sometime during the Upper Silurian period, thus constituting it a peninsula of Appalachia. This condition probably continued until late in the Onondaga age, when the Cincinnati area once more became an island.

The Cincinnati peninsula may have extended as far north as the mouth of the Detroit River, the northern limit of the Silurian outcrop; but in this there is an element of uncertainty, since preglacial and glacial erosion might have removed the Devonian formations which may have covered the northern end of this tongue of land. But whatever the extent of this island or peninsula, the sea which surrounded it, wholly or in part, was continuous over a large part of the southern peninsula of Michigan, portions of Ontario, New York, and Pennsylvania, as well as Kentucky, Tennessee, Indiana, and Illinois.

By the beginning of the Hamilton—that is, the Erian epoch—great changes had occurred. The small gulf in eastern Ohio had expanded into the Cumberland basin, the Cincinnati island was again free from the mainland, and the Traverse strait formed a means of communication between the Dakota and Mississippian seas; but the Kankakee peninsula still formed an effective barrier between this western sea and the Indiana basin of the Mississippian.[3] In

[1] A paper read before the Biological Club of the Ohio State University, February 4, 1907. The work on this subject was done while a graduate student at the university (1905–6), and during the succeeding summer; hence it contains many of the ideas and suggestions of Professor Prosser.

[2] *New York State Museum Bulletin No. 52* (1901), p. 648.

[3] Schuchert, *American Geologist*, Vol. XXXII, pp. 143–62, and Plates XX, XXI.

other words, a great period of sea encroachment had set in which affected mainly the northwestern coast of Appalachia and the land area beyond the Indiana basin. Ohio therefore lay beneath the same sea, much enlarged since the earlier Devonian, as that covering the southern portion of New York in Hamilton time, and naturally contains deposits contemporaneous with those of New York.

As at present defined, the Devonian system in Ohio comprises the following formations:[1]

4. Ohio shale { c) Cleveland shale; b) Chagrin formation; a) Huron shale }
3. Olentangy shale
2. Delaware limestone
1. Columbus limestone

The Columbus limestone is the southern extension of the Dundee of Michigan and the eastern extension of the Jeffersonville of Indiana and Kentucky. This equivalence is shown, not only by lithological similarity and stratigraphic identity, but conclusively by the faunal unity. These Indiana, Michigan, and Ohio limestones are but the local representatives of the Onondaga of New York, or, if we accept the conclusion of Ulrich and Schuchert,[2] which is also supported by Dr. J. M. Clarke,[3] that the Onondaga fauna invaded the state from the west, perhaps it is better to say that the Onondaga limestone is but the New York representative of these limestones.

But what of the Delaware limestone? Newberry and Orton included it with the Columbus as the Ohio equivalent of the "Corniferous" (Onondaga).[4] This, however, seems to have resulted mainly from a mistaken correlation of the deposits occurring in the eastern part of Sandusky,[5] where the upper layers of the Columbus limestone show some variation, both lithological and faunal, from that of the vicinity of the city of Columbus, and approach somewhat the appearance of the true Delaware. Professor Winchell, however,

[1] Prosser, *Report of the Geological Survey of Ohio*, Fourth Series, Bulletin No. 7, p. 3.

[2] *Loc. cit.*, pp. 652, 653, 663.

[3] *Ibid.*, pp. 667, 668.

[4] *Report of the Geological Survey of Ohio*, Vol. I, Part 1, pp. 144, 150, 151; Vol. II, Part 1, pp. 190–92, also 290, 3d note; Vol. III, p. 606.

[5] Prosser, *Journal of Geology*, Vol. XIII, No. 5 (1905), pp. 439–42.

having made an extensive study of these outcrops over the state, pronounced them of Hamilton age.[1] Dr. Newberry agreed that the Olentangy shale, or at least the deposit immediately overlying his "Corniferous" in the northern part of this state, may be Hamilton,[2] and this was evidently supported by the fauna of the Prout limestone, a thin fossiliferous layer occurring immediately below the Huron shale in northern Ohio, but he strenuously objected to the correlation of the Delaware with the Hamilton of the east.[3]

Some time later (1878) Dr. Whitfield visited central Ohio and discovered the brown shale carrying a Marcellus fauna at the base of the Delaware. This, he says, forms "a dividing line between the lower and upper Devonian, as between the limestones of the Upper Helderberg and those that properly refer to the Hamilton period."[4]

Again referring to Ulrich, Schuchert, and Clark, we find that the Marcellus shale fauna very likely entered southeastern New York from the Atlantic, and thence spread westward.[5] Deposits of unquestioned Onondaga in western New York are in all probability contemporaneous with true Marcellus deposits in the eastern part of the same state.[6] This may also be true of the upper part of the Columbus limestone, but the finding of Marcellus deposits in this vicinity (Columbus), even though meager, proves that "the invasion of the black muds which produced the Marcellus beds, and with these the diminutive fauna characteristic of these beds," reached as far west as central Ohio, and hence marks an epoch of change which cannot easily be overlooked. By the time this Marcellus invasion had reached the eastern shore of the Cincinnati island its impetus seems to have been nearly exhausted, as the brown, shaly portion of the Delaware measures but 6 feet and does not occur at all in Indiana, nor does it appear to be recognized in Michigan.

About this time the Hamilton invasion began. The species

[1] *Report of the Geological Survey of Ohio*, Vol. II, Part 1, pp. 244, 289–94, 338, 339, 426, 427, etc.

[2] *Ibid.*, pp. 189, 190.

[3] *Ibid.*, Vol. 1, Part 1, p. 144; Vol. II, Part 1, p. 290.

[4] *Proceedings of the American Association for the Advancement of Science*, Vol. XXVIII (1880), p. 298.

[5] *Loc. cit.*, pp. 665, 668.

[6] Grabau, *New York State Museum Bulletin No. 92*, p. 231.

characteristic of this fauna, Dr. Clarke tells us,[1] invaded New York from the west, part coming up through the Indiana basin and another part through the Traverse strait from the Dakota sea, but the great majority of the species were probably developed from the Onondaga fauna of the northwestern Mississippian sea. Professor Schuchert thinks that the Connecticut channel still continued to admit a few European species during the Hamilton time,[2] but Dr. Grabau says that its efficiency "was greatly diminished."[3] We thus see the heterogeneous character of the Hamilton fauna, which is most marked in regions, such as Ontario and western New York, where all of these elements blended, and thus an excuse, in more isolated regions, for great variation even in true faunas of this age.

Following the base of the Delaware northward, it soon loses its shaly character, and yet even at Stratford, 20 miles north of Columbus, blocks of the massive blue layers from this horizon split into thin, somewhat shaly fragments after extensive weathering, and still contain the same fauna characteristic of these beds in Franklin County. Above the 6-foot shaly zone occur 30 feet of blue limestones, varying from thin-bedded to massive, and sometimes, as at Delaware and Owen, having bands of soft, blue shale from a few inches to a foot in thickness, at different horizons. In Franklin County the formation contains much black chert, which usually occurs as layers alternating with limestone, or sometimes taking the nature of zones; but northward the amount of this material decreases, until at Sandusky little or none occurs. In studying this formation and its fauna, it appears to me that this physical feature has been an influential factor in classifying this deposit among the "Corniferous" rocks. There is little in the lithological appearance of this formation, it is true, which suggests the soft, blue shales of the Eighteen Mile Creek outcrops, except perhaps its persistent blue color; but, on the other hand, the Hamilton deposits of Indiana and Michigan are mainly limestones. It appears, then, that the distinction must rest on the faunal evidence which may be extracted from the various outcrops.

The important outcrops of this formation follow the eastern and

[1] *New York State Museum Bulletin No. 52*, p. 669.

[2] Schuchert, *American Geologist*, Vol. XXXII, p. 162.

[3] Grabau, *New York Museum Bulletin No. 92*, p. 233.

northwestern shores of the Cincinnati island. Taking up first the eastern shore, some forty outcrops of the Columbus have been visited and from these a total of nearly 175 distinct species have been collected, and many more reported by other collectors. The Columbus sea, in other words, was a veritable aquarium in which flourished one of the richest faunas that geological history records. Twenty-five sections, in which the Delaware limestone outcrops, have been examined, and from these a fauna of 71 species has been obtained. Among these we find the following relation: 25 Hamilton species; 16 "Corniferous"-Hamilton species; 13 "Corniferous" species, of which perhaps 3 were originally described from the Delaware and at least do not occur in the Columbus limestone; 17 species (mainly *Corals* and *Bryozoa*) unidentified. Among the Hamilton species are such as, *Lingula ligea* Hall, *Camarotœchia prolifica* Hall, *Ambocœlia umbonata* (Conrad), *Camrotœchia sappho* Hall, *Spirifer audaculus macronotus* Hall, *Chonetes scitulus* Hall, *Glyptodesma erectum* Conrad, *Nyassa arguta* Hall, *Grammysia bisulcata* (Conrad), *Sphenotus cuneatus* (Conrad)—a collection of species which is hard to bring into the "Corniferous" (Onondaga) category.

In northwestern Ohio the evidence is even stronger. Here the rocks rise very little above drainage level, hence a good section is hard to obtain, but along Ten Mile Creek and Auglaize River, at opposite ends of the line of outcrop, fair sections may be found. These two agree in all essentials, both lithologically and paleontologically. Of the 27 feet, all quite fossiliferous, exposed along Ten Mile Creek, the lower 6 feet are soft, blue shales or shaly limestones, followed by 11 feet of soft and compact, blue to drab limestone, with a considerable amount of white chert, and capped by 10 feet of massive, compact, drab limestone. This section compares favorably with that of the Traverse of Michigan; in fact, it is but a continuation of the outcrops of that formation in Monroe County.

Fifty-nine species were collected from this locality and range as follows: 33 Hamilton species; 10 "Corniferous"-Hamilton species; 6 "Corniferous" species; 10 species unindentified. Among the fossils from this section are the following characteristic Hamilton species: *Favosites hamiltoniae* Hall, *Favosites nitella* Winchell, *Heliophyllum halli* Edwards and Haime, *Strombodes alpenensis* Rominger,

Chonetes scitulus Hall, *Spirifer pennatus* (Atwater), *Leiorhynchus laura* (Billings), *Pleurotomaria sulcomarginata* (Conrad), *Tentaculites bellulus* Hall, *Phacops rana* (Green).

No argument is sufficiently strong to place such a collection of species on the Onondaga list. It is, in fact, a true Hamilton fauna.

How much of southeastern Ohio may contain Marcellus deposits, or to what extent, we do not know, but it is certain that the eastern shore of the Cincinnati island felt the effects of the changed conditions which this invasion brought about, while Franklin and Delaware Counties have recorded a trace of the black muds which these swampy seas have left. The impoverished and diminutive fauna which we find in the base of the Delaware proves that the luxuriant life which flourished during the Columbus stage was all but blotted out, and when more favorable conditions were restored, approaching, although never reaching, those which had previously existed, it was not the same fauna that took possession, but one composed of the few surviving Columbus species and a new lot probably wandering south from the hoards which were invading New York at this time. On the northwest coast of the island, however, conditions were different. It is probable that the Marcellus invasion never reached this point, but that the change from the Columbus to the Delaware fauna was gradual. Unfortunately the outcrops visited did not show the contact of these two formations, but the upper part of the Columbus in the sections of that part of the state shows evidence of a marked change in the fauna, which, by the time the shale-forming conditions of the Ten Mile Creek section had set in, had reached a complete conversion into that of the Traverse-Hamilton. To a certain extent the same is true at Sandusky, where these changes in progress in the upper part of the Columbus misled even Dr. Newberry and caused him to call it Delaware. The difference between the Delaware outcrops in the northwestern and central parts of the state may be accounted for in part by supposing, what seems to have been the case, that a spur or peninsula from the Cincinnati island extended as far northward, perhaps, as the present Canadian shore of Lake Erie, thus forming a more or less effective barrier against the fauna which was crowding eastward, and that in this somewhat protected central part of the state the Hamilton invasion was less intense, and thus

the few remaining "Corniferous" species were better able to survive.

Gathering all of the available evidence, there seems to be no substantial support for any other conclusion than that the base of the Delaware marks the beginning of the Hamilton period in Ohio.

Whether the Olentangy shale also belongs to the Hamilton or Erian period, or how much of the deposits above the Delaware limestone belong to that age, is beyond the intentions of this paper. There are some reasons for believing that this shale should rather be classed with the succeeding formation, since other bands of a very similar if not identical, lithological nature occur within what is considered the Ohio shale. It seems certain, however, that Dr. Newberry's Prout Station section is Hamilton.[1] If this be the northern equivalent of the Olentangy shale, as is very generally supposed, there can be no further question as to its age, and the total thickness of the Hamilton in central Ohio is then at least 60 feet.

In the northwestern part of the state the Olentangy shale is apparently wanting, so that the limestones and shales (Traverse) succeeding the Columbus limestone probably represent both the Delaware limestone and the Olentangy shale in that section. The relations existing between these deposits in Ohio, Michigan, and New York may then be stated somewhat as follows:

Michigan	Ohio	New York
Traverse group	Olentangy shale Delaware limestone	Hamilton beds Marcellus shale
Dundee limestone	Columbus limestone	Onondaga limestone

[1] *Report of the Geological Survey of Ohio*, Vol. II, Part I, p. 188.

REVIEWS

Reports on Geological Investigation. By BAILEY WILLIS. Includes: "Geological Exploration in Eastern China," "Studies in Europe," "Geological Research in Continental Histories," and "Artesian Water Conditions at Pekin, China." Washington, D. C. Extract from the ***Fourth Year Book*** of the Carnegie Institution of Washington, 1906. Pp. 192–220.

This paper gives the preliminary results of the author's duties, and his plans for extensive investigation in the future. In Europe he recognizes two general types of mountains: "(*a*) The mountains of central Germany and northern Austria, which were folded at the close of the Paleozoic, were eroded to a peneplain during the Cretaceous, and have since passed through a complex history of warping and erosion; and (*b*) mountains of the Karpathian type, which were folded during the Tertiary, were subsequently eroded to a surface of mature topography, still retaining marked relief, and have since been strongly warped, in some cases before the close of the Tertiary, in others during Quaternary time." The Appalachians belong in class (*a*), the Himalaya probably in class (*b*).

The systematic gathering and publication of existing data on continental histories will be a great boon to science. The problems outlined seem to be largely those set forth in the recent work on geology by Chamberlin and Salisbury. Willis' conclusions, and the development or alteration he may make in the theories of these authors, will be eagerly awaited by all delvers in philosophical geology.

C. W. W.

The Geology of Southern Rhodesia. By F. P. MENNELL, Rhodesia Museum, Bulawayo. Special Report No. 2. Bulawayo, 1904. Pp. 42; 11 figs. and geological map.

This report embraces Mashonaland and Matabeleland, or that part of the Chartered Company's territory which is south of the Zambesi River. The geology is, in many respects, similar to that of the interior of North America.

The Archean consists of schists and gneiss derived from both sedimentary and igneous material. The great granitic masses occupying nearly one-third of the territory and formerly regarded as part of the Archean are shown to be intrusive batholiths.

The Archean is succeeded by what the author calls the Eparchean,[1] which he says may be called also the

Banded Ironstone Series, from the usual name of their principal member. The characteristic feature of these beds is the peculiar banded, flinty rock, which appears under the microscope to be in all probability an altered, fine-grained, mechanical sediment silicified and highly charged with ferruginous material, arranged in parallel bands. They alternate with sheared conglomeratic and arenaceous beds, slates (phyllites), and gneissic bands, which may result either from the crushing of acid intrusives or of tuffs. These beds are usually almost vertical. . . . .

Any American geologist will notice the resemblance of this series to the Algonkian or Proterozoic. The term Eparchean is inadmissible since Lawson has used it for the erosion interval at the base of the Algonkian.[2]

The presence in Rhodesia of Paleozoic below the Permian is doubtful. The latter is a flat coal-bearing, non-marine series of sandstone, shale, conglomerate, and occasional limestone. The coal promises to be of economic importance. Mesozoic strata are absent.

The Tertiary ("Forest Sandstone") consists of red and white sandstone, with occasional conglomeratic or gravelly beds, bands of shale, or impure limestone, and great quantities of interbedded basaltic lava. The author believes that the sedimentary beds are in large part the result of aggradation in an arid climate. Though he constantly refers to them as lacustrine, his description would accord well with a subaerial origin. The description and photograph (Fig. 8) of the "schist country on the plateau" are strongly suggestive of a peneplain, though it is not described as such.

C. W. W.

Recent Changes in Level in Yakutat Bay Region, Alaska. By RALPH S. TARR AND LAWRENCE MARTIN. (Bulletin of the Geological Society of America, Vol. XVII, pp. 29–64, 1906.) Pls. 12–23.

Recent Changes of Level in Alaska. Reprint from *The Geographical Journal*, July, 1906, pp. 30–43.

No proof of recent shore elevation could be more complete and convincing than that presented by the authors in these papers. Their physiographic evidences are: elevated rock benches, elevated sea caves and

[1] In the Correlation Table (p. 24) this is included in the Archean, though separated in the text (p. 11).

[2] Andrew C. Lawson, "The Eparchean Internal: A Criticism of the Use of the Term Algonkian," *University of California, Bull. Dept. Geology*, Vol. 3, No. 3. Berkeley, Cal., 1902.

chasms, elevated beaches, elevated alluvial fans or deltas, till shore-lines, new reefs and islands, and reclaimed land. The biological evidences are: elevated barnacles, mussels, bryozoans, and other marine organisms, still fresh, with the attached forms clinging to the rocks; also the mingling of land and sea life, parallel lines of stranded driftwood, and destruction of life. There is even human evidence of the uplift: two careful students of old shore-lines, Russell and Gilbert, examined the shores of the bay on parts of the coast where uplifted shore-lines are clearly preserved, the former geologist in 1890 and 1891, the latter in 1899, but three months before the earthquake, yet neither observed any evidence of elevation; the ship of the Harriman expedition, which carried Gilbert, sailed close by the uncharted reefs produced during the earthquake, but the sailing master did not see them; natives on various parts of the bay were disturbed by the earthquake and waves; and they observed many of the phenomena of elevation. In 1905 the authors found alders, not over 4 years old, growing in the rock crevices among barnacles 17 feet above high tide. This array of evidence seems to leave no doubt that changes in level were produced during the earthquakes of September, 1899.

The change of level with reference to the sea was considerable, reaching a maximum of 47 feet, 4 inches. This diastrophism is clearly normal faulting of block type, many of the faults having been observed in the field. With reference to sea-level, one block was depressed; the largest block, about 25 miles long, was raised with differential elevation; the others were not tilted, so far as observed.

It is interesting to note that this contribution by Messrs. Tarr and Martin has a pertinent bearing on the Suess theory of general downward movement in normal faulting, in that they have shown (1) that during earthquakes in September, 1899, fault blocks were separately and differentially elevated, with reference to sea-level; and (2) no withdrawal of the sea from other parts of the coast was observed at that time.

C. W. W.

Notes sur la tectonique de la platforme cristalline de la Russie méridionale. (Text in Russian, summary in French.) By W. Laskarew. Separate from Tome XXIV, *Bulletins du comité géologique*, No. 110. St. Petersburg, 1905.

The region described is a dissected platform of paleozoic and older rocks extending from the Sea of Azov to the Carpathian Mountains. The platform is practically a great horst bounded on all sides by faults. The Podolian horst described by Suess lies on its northwest border. The faults

are mostly repeated normal faults, and vary in age from Carboniferous (post-Devonian) to Oligocene, with most of the movement probably before the Jurassic.

Novel features of the paper are: (1) The relation of the platform to the distribution of gravity (pp. 242–46). A line of deficiency in weight has been traced by J. Collet close to the eastern margin of the platform. (2) The relation of the structure of the platform to the magnetic phenomena (pp. 246–49). At the southern edge of the platform, P. Passalsky observed coincidence between magnetic anomalies and the position of folds, as well as the magnetic character of the rocks. The author ascribes the lack of such coincidence at the northern margin to extensive faulting. (3) The relation of the platform to earthquakes (pp. 249–52). Earthquakes have minimum frequency—about $\frac{4}{10}$ per cent. This low frequency is assigned to cessation of deformation within the region, and to the great number of repeated boundary faults which protect the platform from foreign shocks.

C. W. W.

Geography and Geology of Alaska. By ALFRED H. BROOKS, with a Section on "Climate" by CLEVELAND ABBE, JR., and a topographic map and description thereof by R. U. GOODE. (U. S. Geological Survey, Professional Paper No. 45.) Pp. 327, 32 plates. Washington, D. C., 1906.

The main features of the geography of Alaska are classified and discussed in some detail. Four geographic provinces are recognized: (1) the Pacific Mountain system; (2) the Central Plateau; (3) the Rocky Mountain system, and (4) the Arctic Slope. There are maps showing the position of mountain axes, geology, glaciation, and a large topographic map on a scale of 40 miles to the inch. The term "basin lowlands" is introduced (p. 281, and Fig. 5) for "broad, flat depressions, separated from the encircling highlands by almost unbroken scarps." "One of the characteristic features of this lowland type is that within it the water courses are sluggish and aggradation is going on, while the comparatively narrow channels of exit are being rapidly cut down." All the extensive peneplains of Alaska (Coast Range, Chugach, Yukon, Endicott, and Anaktuvuk) are thought to have been formed during post-Kenai (i. e., post-Eocene) and pre-Pliocene times. The present great difference in elevation of these peneplains is assigned to Pliocene and later deformation. There are a few smaller, less extensive base-levels of Pliocene or more recent date.

C. W. W.

Reconnaisance of Some Gold and Tin Deposits of the Southern Appalachians. By L. C. GRATON; with notes on the Dahlonega Mines, by WALDEMAR LINDGREN. (U. S. Geological Survey, Bulletin No. 293.) Pp. 134, 9 plates. Washington, D. C., 1906.

The tin-ore occurs in ore-shoots of slight lateral extent. The only tin-mineral present is Cassiterite which is regarded as a primary constituent of the pegmatite in which it is found. Most of the production is from the Ross mine, near Gaffney, S. C., which in 1903 produced 35,925 pounds of concentrates, and in 1904, 74,396 pounds, which would average probably 66 per cent. to 70 per cent. tin.

The earliest gold-mining in the United States was probably in this region, but the production is not recorded until 1829, when $3,500 was obtained from placers in Lancaster and Chesterfield Counties, S. C. The total production of the Southern Appalachians has probably been about $10,000,000. In general placer-mining has been profitable, lode-mining unprofitable.

The ore is low grade, averaging $8–$12 gold per ton. Fissure veins of pyritiferous quartz are common. They are notably irregular and non-persistent. The most interesting and productive ores are replacement deposits which occur "in volcanic rocks of the quartz-monzonite-porphyry group, and are most common in the fragmental varieties or tuffs." These deposits are large lenticular bodies of silicious, pyritiferous ore, "forty or fifty to hundreds of feet in length and twenty to several hundred feet in width." Many of them do not extend one hundred feet below the surface, others go down as far as present workings, or several hundred feet. The distribution of the ore-values is suggestive of secondary enrichment by descending solutions. C. W. W.

Geology and Paleontology of the Judith River Beds. By T. W. STANTON AND J. B. HATCHER. With a chapter on "The Fossil Plants," by F. H. KNOWLTON. (U. S. Geological Survey, Bulletin No. 257.) Pp. 174, 19 plates. Washington, D. C., 1905.

The Judith River beds are non-marine Upper Cretaceous sandstones, shales, and clays, with lignite occurring in northern and central Montana and adjacent areas of Canada. The authors have established the fact that the Judith River beds belong to the Montana division, that they are separated from the Laramie above by several hundred feet of shales (Bearpaw shales) with the marine fauna of the Pierre, that they are underlain by marine shales and sandstones which constitute a distinct horizon (Claggett

formation) in the Montana group, and that they are strictly equivalent to the Belly River beds of Canada. The authors believe that the Eagle formation marks the base of the Montana group, that the Bearpaw shales, Judith River beds, Claggett, and Eagle formations belong to the Montana group and are "equivalent to the Pierre as that term is generally understood," and that "the use of the term Fox Hills as a formation or horizon name outside of the original area in South Dakota is of doubtful propriety."

C. W. W.

The Limeless Ocean of Pre-Cambrian Time. By REGINALD A. DALY. (Reprint from *American Journal of Science*, Vol. XXIII, February, 1907, pp. 93–115.)

The concertion of limeless ocean is urged as an explanation of the absence of fossils in non-metamorphic pre-Cambrian rocks. In Eozoic time the lime-salts inherited form Azoic time were precipitated as carbonate, because of the production of ammonium carbonate by decomposing organic matter. This and other conclusions are based on premises some of which are observational and sound, but others are postulates and deductions of indeterminate value. Perhaps unintentionally the author (p. 113, premises 9, 10, 11, and p. 100) has left the impression that the $CaCO_3$ of the sea has been always derived mainly from pre-existing limestone, instead of from decomposed silicates. From the hypothesis interesting deductions are made as to the early development of the hard parts of organisms.

C. W. W.

Rate of Recession of Niagara Falls. By G. K. GILBERT. Accompanied by a Report on the Survey of the Crest. By W. CARVEL HALL. (U. S. Geological Survey, Bulletin No. 306.) Pp. 31, 11 plates. Washington, 1907.

"The rate of recession of the Horseshoe Fall, or the rate of lengthening of the Niagara gorge, during the sixty-three years from 1842 to 1905 is found to be 5 feet per annum, with an uncertainty of 1 foot. For the thirty-three years from 1842 to 1875 the rate was apparently slower than for the thirty years from 1875 to 1905. The rate of recession of the American Fall during the seventy-eight years from 1827 to 1905 was less than 3 inches per annum." The latter figure is of interest to geologists because somewhat representative of the river's activity in gorge-making when the volume of water was much less."

C. W. W.

Geology of the Lower Colorado River. By WILLIS T. LEE. (Bulletin of the Geological Society of America, Vol. XVII [June 23, 1906]. Pp. 275–84, plates 32–24.)

In this interesting paper the origin of the Grand Canyon is placed at the very close of the Tertiary and most of its erosion is assigned to the early Quaternary. During the Pliocene and early Quaternary the Lower Colorado flowed through a broad valley occupied by Virgin River at the north and extending southward 125 miles to the mouth of Williams river. It was deflected from this course by detrital aggradation and lava flows which filled a part of the old valley to a depth of 800 feet. Since then it has lowered its new channel over 2,000 feet and cut Boulder, Black, Needles, and Aubrey canyons. The canyon has since been filled with gravel to a depth of 700 feet, and later re-excavated below its present bottom. At present aggradation is in progress. C. W. W.

Geology and Mineral Resources of Part of the Cumberland Gap Coal Field, Kentucky. By GEORGE HALL ASHLEY AND LEONIDAS CHALMERS GLENN. (U. S. Geological Survey, Professional Paper No. 49.) Pp. 239, 40 plates. Washington, D. C., 1906.

The rocks of this field all belong to the Pottsville group, with a thickness here about 4,000 feet. The lower third of the rocks are mainly sandstones, while the upper two-thirds, carrying the coal beds, are about equally sandstone and shale. The structure is that of a flat-bottomed U-shaped trough; dips do not average more than 100 feet to the mile. There are thirteen workable coals. Eight are mined; thickness, 4 to 6 feet. The output is from 600,000 to 1,000,000 tons a year, used mainly by the L. & N., and the Southern Railways and by a blast furnace at Middlesboro.

C. W. W.

Trent River System and Saint Lawrence Outlet. By ALFRED W. G. WILSON. Rochester, N. Y., 1904. (Bulletin of the Geological Society of America, Vol. XV, pp. 211–42, Plates 5–10.)

The configuration of the Trent River system of eastern Ontario is determined by joints in the Ordovician limestone of that area. Farther north in the Archean, pre-Ordovician faults influence the drainage. Neither glacial erosion nor deposition have been sufficient to obliterate the pre-glacial drainage lineaments determined by joints. But the pre-glacial direction of drainage was prevailingly to the southwest and this has been largely changed by tilting.

The St. Lawrence outlet is a complex of three partly submerged valleys. The straits between the islands mark sags in the inter-basin ridges. The former drainage of the locality was southwestward across the basin of Lake Ontario, in the edge of which many of the pre-glacial channels may be detected by sounding. C. W. W.

Moulin Work Under Glaciers. By G. K. GILBERT. (Bulletin of the Geological Society of America, Vol. XVII, pp. 317–20, plates 40–42.)

Describes, figures, and explains the formation of some interesting examples of complete and incomplete glacial pot-holes.

C. W. W.

Gravitational Assemblage in Granite. By G. K. GILBERT. 1906. (Bulletin of the Geological Society of America, Vol. XVII, pp. 321–28, Plates 43–46.)

The author suggests that gravity may have caused some aggregations of feldspar, and of hornblende, in certain granitic rocks of the Sierra Nevada. The only evidence offered is the observation that these aggregates of phenocrysts are of materials, lighter in one case, heavier in the other, than the rest of the rock; and that there is little granitic material between the phenocrysts.

Some banding observed in the granite is assigned provisionally to deposition under gravitational control. An "unconformity" in this granite is described and photographed (p. 324, Fig. 1, and Plate 44). This is thought to be due possibly to internal magmatic deposition and erosion.

C. W. W.

Post Pleistocene Drainage Modifications in the Black Hills and Bighorn Mountains. By GEORGE ROGERS MANSFIELD. Cambridge, Mass., 1906. (Bulletin of the Museum of Comparative Zoölogy, Vol. XLIX; Geological Series, Vol. VIII, No. 3, pp. 59–87.)

Extensive high deposits of Pleistocene river gravels are described in both districts. The former general courses of the streams that deposited these gravels is determined by an ingenious plot (Plate I) on which each gravel locality is connected with the possible sources of its pebbles. The modification of the Pleistocene stream courses through adjustment, capture, and crustal warping is discussed. The entrenchment of the streams in post-Pleistocene time is assigned "to uplift or broad up-warping, rather than to climatic oscillation." C. W. W.

The Origin and Structure of the Roxbury Conglomerate. By GEORGE ROGERS MANSFIELD. Cambridge, Mass., 1906. (Bulletin of the Museum of Comparative Zoölogy, Vol. XLIX; Geological Series, Vol. VIII, No. 4, pp. 92–271.)

The Roxbury Conglomerate is a series of sediments 5,000 to 12,000 feet thick in and adjacent to the Boston Basin, composed largely of coarse conglomerate, with some sandstone and shale. It is probaply of Carboniferous age.

After a careful analysis of the evidence "largely negative and unsatistory," the author favors a hypothesis of non-marine origin. "Glaciers were not directly concerned with the deposition of the conglomerate, but they probably furnished material to the torrents, by which it was deposited." High grades and mountainous condition prevailed about the area of deposition.

A useful part of the paper is an analytical discussion (45 pages) of the origin of conglomerates in which the known kinds of evidence are classified, described, and weighed. C. W. W.

Paleontology of the Malone Jurassic Formation of Texas. By FRANCIS WHITTEMORE CRAGIN. Washington, D. C., 1905. (U. S. Geological Survey, Bulletin No. 266.) Pp. 109, 29 plates.

In western Texas at Malone Mountain, there are deformed upper Jurassic strata of gypsum, conglomerate, limestone, and shale. The marine fauna is rich and practically identical with that of a number of Mexican localities that lie in line with the Malone occurrence. Many new species are described and figured, including some ammonites that are unfortunately without figures of septa. Cephalopods are not abundant, but the few forms present are decisively upper Jurassic.

The reviewer takes interest in noting that this fauna contains elements, related if not ancestral, to elements in the Pacific Coast Upper Cretaceous, and other elements that have relatives in the succeeding Lower Cretaceous beds of Texas. C. W. W.

Recent Cave Explorations in California. By. JOHN C. MERRIAM. Reprint from *American Anthropologist* (N. S.), Vol. VIII, No. 2, April-June 1906, pp. 221–28.

Dr. Merriam describes the fossils and deposits in four California caves. In the Potter Creek cave, which was formed at the same time as a terrace now 800 feet above the McCloud River, there is about 25 feet of fossil-

iferous stalagmite which has yielded several thousand bones and fragments, of which between 4,000 and 5,000 are determinable specimens. Fifty-two species have been determined, including twenty-one extinct species. The fauna is certainly as old as the middle Quaternary.[1] Associated with these fossils are some pointed and polished bones, fragments, and others with peculiar perforations that seem hard to explain except by human origin. The phenomena of the other caves are similar, though more recent. In one of them were parts of a human skeleton incrusted with stalagmite. But Dr. Merriam is very conservative, and casts doubt both on the human origin of the perforated and polished bones, and on the great antiquity of the human skeleton. C. W. W.

Geology of the Volcanic Area of the East Moreton and Wide Bay Districts, Queensland. By H. I. JENSON. (Proceedings of the Linnean Society of New South Wales, April, 1906, Part I, pp 73–173, Plates V–XVI.)

The physiography, general geology, and petrology are discussed. There are pre-Devonian schist, and gneiss, probably Archean. The Paleozoic, including the Gympic series (Carboniferous ?), is highly metamorphosed. The only other sedimentary rocks are faulted, Jura Trias feldspathic sandstones, with tuff and coal. The igneous rocks include tonalite, granite, aplite, epidiorite, granophyre, quartz-diorite, porphyrite, monzonite, sölusfergite, rhyolite, trachyte, comendite, and pantellerite. These are described petrographically, with chemical analyses, and calculations of their positions in the quantitative system. C. W. W.

Copper Deposits of the Clifton-Morenci District, Arizona. By WALDMAR LINDGREN. (U. S. Geological Survey, Professional Paper No. 43.) Pp. 375, 24 plates. Washington, D. C., 1905.

The three principal mines of this district produced 53,400,000 pounds of copper in 1903. The ores are associated with post-Cretaceous intrusions of acid porphyries, and are thought to have derived their metals directly from the solutions accompanying these intrusions. Most of the ore is in the form of local replacement and impregnation of the country rock through contact metamorphism; circulating atmospheric waters were not concerned in their origin. But there are also some fissure veins of the

[1] See Sinclair, "North American Archaeology and Ethnology," *Publications of the University of California*, Vol. 2, No. 1.

ordinary type. The report discusses the general geology, the ore-deposits and their minerals, with description of one new species, *Coronadite*. There is also an extended discussion of metasomatic processes, and finally a description of the mines and mineral-deposits.

C. W. W.

Slate Deposits and Slate Industry of the United States. By T. NELSON DALE. With sections by E. C. ECKEL, W. F. HILLEBRAND, and A. T. COONS. (U. S. Geological Survey, Bulletin No. 275.) Pp. 154, 25 plates. Washington, D. C.

The phenomena of slate are described and explained. The sedimentary slates are classified in two divisions: clay slates and mica slates; and the latter division, which includes all commercial slates, is subdivided into: (1) fading and (2) unfading, according to the presence or absence of sufficient $FeCO_3$ to produce discoloration on weathering. Further subdivision is into: (*a*) graphitic slate, (*b*) hematitic (reddish), (*c*) chloritic (greenish), (*d*) hematitic and chloritic (purplish). The slates of fifteen states are described. Merriam's tests for strength, toughness, density, softness, porosity, and corrodibility are given for a number of slates, and the comparative characteristics discussed. The slate production of the United States in 1903 was $6,256,885; in 1904 it was $5,617,195.

C. W. W.

A Preliminary Reconnaissance of the Mancayan-Suyoc Mineral Region, Lepanto, P. I. By A. J. EVELAND. (Bulletin No. 4, The Mining Bureau, Manila, P. I., 1905. Pp. 58, 42 plates.)

The rocks of this region consist of schists and dioritic rocks of unknown age, Eocene limestone and conglomerate, and volcanics. The ores carry both gold and copper, but are developed only in the most primitive way.

C. W. W.

The Coal Deposits of Batan Island, with Notes on the General and Economic Geology of the Adjacent Region. By WARREN D. SMITH. (Bulletin No. 5, The Mining Bureau, Manila, P. I., 1905. Pp. 56, 21 plates.)

The general region is volcanic and of recent age. Batan, however, is composed largely of folded sedimentaries ranging in age from Eocene to Pleistocene, and resting on pre-Tertiary dolerite and other rocks. There are eleven coal seams of which two are generally workable. The coal is good steam coal.

C. W. W.

Oil Fields of the Texas-Louisiana Gulf Coastal Plain. By N. M. FENNEMAN. (U. S. Geological Survey, Bulletin No. 282.) Pp. 146, 11 plates. Washington, D. C., 1906.

The oil of this region generally occurs beneath low mounds. At depths of 800 to 1,600 feet these mounds contain three substances that are not found in drill-holes away from the mounds, namely: (1) crystalline limestone, frequently dolomitic and usually porous or cavernous; the caverns are filled with oil and frequently they are lined with sulphur crystals; (2) gypsum, both the massive rock and as an admixture in sands and clays, occuring nearly always below the limestone; (3) rock salt and salt solutions impregnating sand, occuring below the gypsum. The oil is associated with the limestone and with the overlying unconsolidated sands. The position of the mounds is marked by rising ground water as indicated by the temperature and salinety of the water. It is thought that these rising waters have introduced and segregated the limestone, gypsum, and salt under the mounds. Possibly the pressure extorted during the growth and alteration of the bodies of limestone, gypsum, and salt has been sufficient to raise the mounds. C. W. W.

The Constitution of the Interior of the Earth as Revealed by Earthquakes. By R. D. OLDHAM. (Quarterly Journal of the Geological Society, Vol. LXII, 1906, pp. 456–73. London, 1906.)

The author agrees with most recent seismologists in believing that the core of the earth does not transmit tremors with the facility of the rest of the planet. He does not suggest whether this inability to transmit waves is due to a composition of iron, compressed gas, or other substance. The central core occupies about four-tenths of the diameter of the earth. "The interior of the earth after the outermost crust of heterogeneous rock is passed, consists of a uniform material, capable of transmitting wave-motion of two different types at different rates of propagation; this material undergoes no material change in physical character to a depth of six-tenths of the radius." C. W. W.

The Geological Map of Illinois. By STUART WELLER. Illinois State Geological Survey, H. Foster Bain, Director. Bulletin No. 1. Urbana: University of Illinois, 1906.

This is a provisional geological map in twelve colors, scale 12 miles to the inch. It is accompanied by 25 pages of text descriptive of the formations and structure. C. W. W.

Types of Sedimentary Overlap. By AMADEUS W. GRABAU. (Bulletin of the Geological Society of America, Vol. XVII, pp. 567–636.) Rochester, N. Y., 1906.

The two main types of progressive sedimentary overlap are the marine, in which successive beds overlap toward the source of supply, and the non-marine, in which they overlap progressively away from the source of supply. Phenomena of overlap are described in detail, and the principles deduced from them are applied to the basal Paleozoic series, the basal Mesozoic series, the Devonian Black Shale problem, Saint Peter sandstone, Dakota sandstone, the Chemung-Catskill, Pocono, Mauch Chunk, Pottsville, and other examples. The author has reached the conclusion that the Black Shale of the southern Appalachians is Mississippian.

C. W. W.

Interglacial Periods in Canada. By A. P. COLEMAN. Imprenta y fototipía de la Secretaría de Fomento, México. Callejón de Betlemitas numero 8, 1906.

In this paper, which was read before the Mexican meeting of the Geological Congress (1906), the author shows "that extensive interglacial beds of at least three ages occur in Canada, the oldest in British Columbia and Alberta; two later ones, probably between the Illinoian and Iowan, and the Iowan and Wisconsin ice ages, in southern and northern Ontario. Extensive interglacial periods have not yet been disclosed in eastern Canada, though an interesting lignite bed in Cape Breton island is probably interglacial. The most thoroughly studied interglacial formation, that of Toronto, has furnished a large flora and fauna showing temperate conditions."

C. W. W.

The Shelburne and South Bend Meteorites. By OLIVER CUMMINGS FARRINGTON. (Publication No. 109, Field Columbian Museum Geological Series, Vol. III, No. 2. Pp. 23, 18 plates. Chicago, 1906.)

The Shelburne, Ont., meteorite is a stony meteorite consisting of enstatite, chrysolite, and subordinate troilite and nickel—iron. The South Bend, Ind., meteorite consists of 78 per cent. chrysolite and 21 per cent. nickel-iron. The fall of the former was observed.

C. W. W.

Recent Publications

KOKEN, E. Geologische Beiträge aus Südtirol. [Separat-Abdruck aus dem Neuen Jahrbuch für Mineralogie, Geologie, und Paläontologie. Jahrg. 1906. Bd. II. S. 1919 und Taf. I–III. Stuttgart, 190–.]

———Productus Purdoni im Perm von Kaschmir. [Separat-Abdruck aus dem Centralblatt für Mineralogie, Geologie, und Paläontologie. Jahrg. 1906. No. 5. Stuttgart, 1906.]

—KÜMMEL, H. B. Annual Report of the State Geologist for the Year 1905. [Geological Survey of New Jersey. Trenton, 1906.]

—KUSAKABE, S. A Note on the Direction of Earthquake Motion. [Proceedings of the Tokyo Physico-Mathematical Society, Vol. III, No. 1. February, 1906.]

———Frequency of After-Shocks and Space-Distribution of Seismic Waves. [Journal of the College of Science, Imperial University, Tokyo, Japan, Vol. XXI, Article 1. Tokyo, Japan, 1906.]

—KUNZ, G. F. The Production of Precious Stones in 1905. [Extract from Mineral Resources of the United States, Calendar Year 1905. U. S. Geological Survey, Washington, 1906.]

—LAMBE, F.G.S., F.R.S.C., L. M. On Amyzon brevipinne, Cope, from the Amyzon beds of the Southern Interior of British Columbia. [From the Transactions of the Royal Society of Canada. Second Series—1906–1907. Volume XII, Section IV. Ottawa, 1906.]

—LANE, A. C. Die Korngrösse der Auvergnosen. Stuttgart, 1906.

———Review of Dr. Heinrich Ries's Economic Geology of the United States. [Reprinted from Science, N. S., Vol. XXIII, No. 580, pp. 225–27, February 9, 1906.]

———The Influence of Varying Degrees of Superfusion in Magmatic Differentiation. [Journal of Canadian Mining Institute. Part of Vol. IX.]

———The Interior of the Earth. [Reprinted from Science, N. S., Vol. XXIV, No. 613, pp. 404, 405, September 28, 1906.]

———The Possibility of Deep Cracks in the Earth. [Reprint from The Michigan Miner, May, 1906.]

—LAWSON, A. C. Preliminary Report of the State Earthquake Investigation Commission. Berkeley, Cal., May 31, 1906.

———The Copper Deposits of the Robinson Mining District, Nevada. [University of California Publications, Bulletin of the Department of Geology. Vol. IV, No. 14, pp. 287–357. Berkeley, May, 1906.]

———The Geomorphic Features of the Middle Kern. [University of California Publications. Bulletin of the Department of Geology, Vol. IV, No. 16, pp. 397–409, Pls. 38–41. Berkeley, September, 1906.]

———The Geomorphogeny of the Telachapi Valley System. [University of California Publications. Bulletin of the Department of Geology, Vol. IV, No. 19, pp. 431–62, Pls. 42–51. Berkeley, September, 1906.]

—LEE, W. T. Geology of the Lower Colorado River. [Bulletin of the Geological Society of America, Vol. XVII, pp. 275–84, Pls. 32–34. Rochester, June, 1906.]

———Water Resources of the Rio Grande Valley in New Mexico and Their Development. [U. S. Geological Survey. Water-Supply and Irrigation Paper No. 188. Series B, Descriptive Geology, 108. Series O, Underground Waters, 66. Washington, 1907.]

—LEITH, C. K. Iron Ore Reserves. [Reprinted from Economic Geology, Vol. I, No. 4, 1906.]

—LEVERETT, F., AND OTHERS. Flowing Wells and Municipal Water Supplies in the Middle and Northern Portions of the Southern Peninsula of Michigan. [U. S. Geological Survey. Water-Supply and Irrigation Paper No. 183. Series O, Underground Waters, 63. Washington, 1907.]

———Flowing Wells and Municipal Water Supplies in the Southern Portion of the Southern Peninsula of Michigan. [U. S. Geological Survey. Water-Supply and Irrigation Paper No. 182. Series O, Underground Waters, 62. Washington, 1906.]

—LEVERETT, F., VAUGHAN, V. C., WILLIAMS, G. S., LEIGHTON, M. O., RUSSELL, I. C. Symposium on Water Supplies in Michigan. [Reprinted from the Eighth Annual Report of the Michigan Academy of Science.]

—LEWIS, A. W. A New Illinois Oil Field. [The Mining World, April 14, 1906.]

—LEWIS, J. V. An Ontario Lead Deposit. [Reprinted from Economic Geology, Vol. I, No. 7, July–August, 1906.]

—LEWIS, S. J. Quality of Water in the Upper Ohio River Basin and at Erie, Pa. [U. S. Geological Survey. Water-Supply and Irrigation Paper No. 161. Series L, Quality of Water, 13. Washington, 1906.]

—LULL, PH.D., R. The Evolution of the Horse Family. [Yale University. Peabody Museum of Natural History, Guide No. 1. Reprinted from The American Journal of Science, Vol. XXIII, March, 1907.]

—MANSFIELD, G. R. The Origin and Structure of the Roxbury Conglomerate. [Bulletin of the Museum of Comparative Zoölogy at Harvard College, Vol. XLIX. Geological Series, Vol. VIII, No. 4. Cambridge, Mass., November, 1906.]

—MARR, SC.D., F.R.S., JOHN EDWARD. Address delivered at the Anniversary Meeting of the Geological Society of London, on February 16, 1906. [London, 1906.]

—McCaskey, H. D. Sixth Annual Report of the Chief of the Mining Bureau to the Honorable Secretary of the Interior, Being for the Year Ended August 31, 1905. Manila, 1906.

—McCourt, W. E. Fire Tests of Some New York Building Stones. [New York State Museum. Bulletin 100. Economic Geology 14. Albany, 1906.]

—Mead, G. H. The Teaching of Science in College. [Reprinted from Science, N. S., Vol. XXIV, No. 613, pp. 390–97, September 28, 1906.]

—Merriam, J. C. On the Occurrence of Desmostylus, Marsh. [Reprinted from Science, N. S., Vol. XXIV, No. 605, pp. 151, 152, August 3, 1906.]

———The Occurrence of Ichthyosaur-like Remains in the Upper Cretaceous of Wyoming. [Reprinted from Science, N. S., Vol. XXII, No. 568, pp. 640, 641, November 17, 1905.]

—Merrick, M.W.S.E., A. W. The Clay Slide at the Boone Viaduct, Boone, Iowa. [Western Society of Engineers, Chicago, April 4, 1906.]

—Merrill, G. P. Notes on the Composition and Structure of the Hendersonville, North Carolina, Meteorite, with Chemical Analysis by Wirt Tassin. [No. 1511. From the Proceedings of the United States National Museum, Vol. XXXII, pp. 79–82, with Pls. VIII, IX. Washington, 1907.]

———On a Newly Found Meteorite from Selma, Dallas County, Alabama. [No. 1508. From the Proceedings of the United States National Museum, Vol. XXXII, pp. 59–61, with Pls. VI, VII. Washington, 1907.]

—Mining and Geological Institute of India, Transactions of the. [Vol. I, Part 1. Calcutta, May, 1906.]

—Moritz, C.E., E. A. Tests on Reinforced Concrete Beams. [Bulletin of the University of Wisconsin, No. 148. Engineering Series, Vol. III, No. 4, pp. 319–94.]

—Mossman, F.R.S.E., R. C. Some Meteorological Results of the Scottish National Antarctic Expedition. [Reprinted from The Scottish Geographical Magazine for May, 1906. Edinburgh.]

—National Academy of Sciences, Report of the, for the Year 1906. Washington, 1907.

—Nipher, F. E. On Pressure Measurements in a Fluid Stream. [Transactions of The Academy of Science of St. Louis. Vol. XVI, No. 3.]

—Obalski, J. Mining Operations in the Province of Quebec for the Year 1905. [Department of Colonization, Mines, and Fisheries. Quebec, April, 1906.]

—Oberholsei, H. C. The North American Eagles and Their Economic Relations. [U. S. Department of Agriculture. Biological Survey-Bulletin No. 27. Washington, 1906.]

—Oldham, R. D. Constitution of the Interior of the Earth. [Quarterly Journal of the Geological Society, Vol. LXII, 1906, pp. 456–73.]

-Ortmann, A. E. Mexican, Central American, and Cuban Cambari. [Proceedings of the Washington Academy of Sciences. Vol. VIII, pp. 1–24. Washington, May 3, 1906.]

—Park, M. Inst. M. and M. (London), M.A. Inst. M.E., F.G.S. (London), James. The Geology of the Area Covered by the Alexandra Sheet, Central Otago Division. [Department of Mines, New Zealand Geological Survey. Bulletin No. 2 (New Series). Wellington, New Zealand, 1906.]

—Parr, S. W. Composition and Character of Illinois Coals. With Chapters on the Distribution of the Coal Beds of the State, by A. Bement, and Tests of Illinois Coals under Steam Boilers, by L. P. Breckenridge. [Illinois State Geological Survey. Bulletin No. 3. Urbana, 1906.]

—Penck, A. Climatic Features of the Pleistocene Ice Age. [From The Geographic Journal for February, 1906.]

———Plan of a Map of the World—Recent Progress in the Execution of a Map of the World on the Uniform Scale of 1:1,000,000 (916 miles to the inch). [Vienna.]

—Philippi, E. Die Störungen der Kreide und des Diluviums aus Jasmund und Arkona (Rügen). [Sonder-Abdruck aus Zeitschrift für Gletscherkunde. I. Band. Berlin, 1906.]

———Ueber Facettengeschiebe aus norddeutschem Diluvium. [Separat-Abdruck aus dem Neuen Jahrbuch für Mineralogie, Geologie, und Paläontologie. Jahrg. 1906. Bd. I. S. 71–80 und Taf. VIII. Stuttgart, 1906.]

—Phelps, E. B. The Prevention of Stream Pollution by Strawboard Waste. [U. S. Geological Survey. Water-Supply and Irrigation Paper, No. 189. Series L, Quality of Water, 17. Washington, 1906.]

—Pirie, B.Sc., M.B., J. H. H. A Note on the Geology of Gough Island. Also Notes on the Petrology of Gough Island, by R. Campbell, M.A., B.Sc. [Reprint from the Proceedings of the Royal Physical Society of Edinburgh. Session 1905–06. Vol. XVI, No. 6. Edinburgh, March, 1906.]

—Pirsson, L. V. Samuel Lewis Penfield, 1856–96. [Am. Jour. Sci., Fourth Series, Vol. XXII, No. 131. November, 1906.]

—Platania, Giovanne e Platania, Gaetano. Sul Magnetismo Prodotto da Fulminazioni. [Estratto dalle Memorie della Classe di Scienze della R. Accademia degli Zelanti. 3a serie. Vol. IV. 1905–06. Acireale, 1906.]

—Prindle, L. M. The Yukon-Tanana Region, Alaska. Description of Circle Quadrangle. [U. S. Geological Survey, Bulletin No. 295. Series A, Economic Geology, 82. Series B, Descriptive Geology, 101. Washington, 1906.]

—Pumpelly, R. Interdependent Evolution of Oases and Civilizations. [Bulletin of the Geological Society of America. Vol. XVII, pp. 637–70. Rochester, December, 1906.]

—RAYMOND, P. E. On the Occurrence, in the Rocky Mountains, of an Upper Devonian Fauna with Clymenia. [From The American Journal of Science, Vol. XXIII, February, 1907.]

—REID, H. F. The Flow of Glaciers and Their Stratification. [Extracted from Appalachia, Vol. XI, No. 1.]

—Réunion extraordinaire de la Société Géologique de France en Italie, à Turin et à Gênes du mardi 5 au mardi 12 septembre 1905. [Nos. 14 et 15 Compte Rendu Sommaire des Séances de la Société Géologique de France.]

—RICHARDSON, G. B. Under-Ground Water in the Valleys of Utah Lake and Jordan River, Utah. [Water-Supply and Irrigation Paper No. 157. Series B, Descriptive Geology, 86. Series O, Under-Ground Waters, 53. Washington, 1906.]

—RIES, H. The Clays of Texas. [Transactions of the American Institute of Mining Engineers. London Meeting, July, 1906. Published by permission of the director of the University of Texas Mineral Survey.]

—RIGGS, E. S. The Carapace and Plastion of Basilemys Sinuosus, a New Fossil Tortoise from the Laramie Beds of Montana. [Field Columbian Museum. Publication 110. Geological Series, Vol. II, No. 7. Chicago, February 1, 1906.]

THE

JOURNAL OF GEOLOGY

OCTOBER-NOVEMBER, 1907

PERMO-CARBONIFEROUS CLIMATIC CHANGES IN SOUTH AMERICA

DAVID WHITE

INTRODUCTION

The presence in Argentina and Brazil of representatives of the Lower Gondwana, or *Gangamopteris* flora has for some years been

In the absence of the managing editors the name of the author of Dr. H. F. Cleland's article in the last issue of the Journal of Geology was omitted. Our apologies are due the author and readers alike for this inexcusable oversight. Will each subscriber kindly paste the accompanying slip at the head of the article entitled, "Restorations of Certain Devonian Cephalopods with Descriptions of New Species" by Dr. H. F. Cleland, Williams College, Williamstown, Mass., in the Journal of Geology No. 5, page 459.

RESTORATIONS OF CERTAIN DEVONIAN CEPHALOPODS WITH DESCRIPTIONS OF NEW SPECIES

H. F. CLELAND
Williams College, Williamstown, Mass.

—Raymond, P. E. On the Occurrence, in the Rocky Mountains, of an Upper Devonian Fauna with Clymenia. [From The American Journal of Science, Vol. XXIII, February, 1907.]

—Reid, H. F. The Flow of Glaciers and Their Stratification. [Extracted from Appalachia, Vol. XI, No. 1.]

—Réunion extraordinaire de la Société Géologique de France en Italie, à Turin et à Gênes du mardi 5 au mardi 12 septembre 1905. [Nos. 14 et 15 Compte Rendu Sommaire des Séances de la Société Géologique de France.]

—Richardson, G. B. Under-Ground Water in the Valleys of Utah Lake and Jordan River, Utah. [Water-Supply and Irrigation Paper No. 157. Series B, Descriptive Geology, 86. Series O, Under-Ground Waters, 53. Washington, 1906.]

—Ries, H. The Clays of Texas. [Transactions of the American Institute of Mining Engineers. London Meeting, July, 1906. Published by permission of the director of the University of Texas Mineral Survey.]

—Riggs, E. S. The Carapace and Plastion of Basilemys Sinuosus, a New Fossil Tortoise from the Laramie Beds of Montana. [Field Columbian Museum. Publication 110. Geological Series, Vol. II, No. 7. Chicago, February 1, 1906.]

THE

JOURNAL OF GEOLOGY

OCTOBER–NOVEMBER, 1907

PERMO-CARBONIFEROUS CLIMATIC CHANGES IN SOUTH AMERICA

DAVID WHITE

INTRODUCTION

The presence in Argentina and Brazil of representatives of the Lower Gondwana, or *Gangamopteris* flora has for some years been definitely recognized through the small collections examined by Professors Zeiller[1] and Kurtz.[2] More recently, however, the Coal Commission of Brazil has placed in the writer's hands a number of fossil plant collections which, though lacking much both in quantity and preservation, are definitely fixed stratigraphically, while embracing a considerable vertical range.

The new material, from the coalfields, chiefly of the states of Santa Catharina and Rio Grande do Sul, in Brazil, not only confirms the presence in that country of the Lower Gondwana flora, but it also throws new light on the geographical relations and climatic changes in this quarter of the earth during Permo-Carboniferous time. The purpose of this paper is particularly to call attention to some of the physical conditions indicated with more or less distinctness by the fossil floras, and briefly to state the conclusions drawn or opinions entertained by the writer in an attempt to account for certain changes in climate.

[1] *Comptes Rendus*, Vol. CXXI, 1895, p. 961; *Bull. Soc. géol. Fr.* (3), Vol. XXIII, 1896, p. 601.

[2] *Rev. Mus. de la Plata*, Vol. VI, 1894, p. 125; *Bull. Soc. géol. Fr.* (3), Vol. XXIV, 1896, p. 466.

—RAYMOND, P. E. On the Occurrence, in the Rocky Mountains, of an Upper Devonian Fauna with Clymenia. [From The American Journal of Science, Vol. XXIII, February, 1907.]

—REID, H. F. The Flow of Glaciers and Their Stratification. [Extracted from Appalachia, Vol. XI, No. 1.]

—Réunion extraordinaire de la Société Géologique de France en Italie, à Turin et à Gênes du mardi 5 au mardi 12 septembre 1905. [Nos. 14 et 15 Compte Rendu Sommaire des Séances de la Société Géologique de France.]

—RICHARDSON, G. B. Under-Ground Water in the Valleys of Utah Lake and Jordan River, Utah. [Water-Supply and Irrigation Paper No. 157. Series B, Descriptive Geology, 86. Series O, Under-Ground Waters, 53. Washington, 1906.]

—RIES, H. The Clays of Texas. [Transactions of the American Institute of Mining Engineers. London Meeting, July, 1906. Published by permission of the director of the University of Texas Mineral Survey.]

—RIGGS, E. S. The Carapace and Plastion of Basilemys Sinuosus, a New Fossil Tortoise from the Laramie Beds of Montana. [Field Columbian Museum. Publication 110. Geological Series, Vol. II, No. 7. Chicago, February 1, 1906.]

THE
JOURNAL OF GEOLOGY

OCTOBER–NOVEMBER, 1907

PERMO-CARBONIFEROUS CLIMATIC CHANGES IN SOUTH AMERICA

DAVID WHITE

INTRODUCTION

The presence in Argentina and Brazil of representatives of the Lower Gondwana, or *Gangamopteris* flora has for some years been definitely recognized through the small collections examined by Professors Zeiller[1] and Kurtz.[2] More recently, however, the Coal Commission of Brazil has placed in the writer's hands a number of fossil plant collections which, though lacking much both in quantity and preservation, are definitely fixed stratigraphically, while embracing a considerable vertical range.

The new material, from the coalfields, chiefly of the states of Santa Catharina and Rio Grande do Sul, in Brazil, not only confirms the presence in that country of the Lower Gondwana flora, but it also throws new light on the geographical relations and climatic changes in this quarter of the earth during Permo-Carboniferous time. The purpose of this paper is particularly to call attention to some of the physical conditions indicated with more or less distinctness by the fossil floras, and briefly to state the conclusions drawn or opinions entertained by the writer in an attempt to account for certain changes in climate.

[1] *Comptes Rendus*, Vol. CXXI, 1895, p. 961; *Bull. Soc. géol. Fr.* (3), Vol. XXIII, 1896, p. 601.

[2] *Rev. Mus. de la Plata*, Vol. VI, 1894, p. 125; *Bull. Soc. géol. Fr.* (3), Vol. XXIV, 1896, p. 466.

The stratigraphical series in the coal basins of the state of Santa Catharina as published by Dr. I. C. White, late chief of the commission, is essentially as follows:[1]

Santa Catharina System:

São Bento Series:	Serra Geral eruptives. Botucatú sandstones, great cliffs of red, gray, and cream-colored sandstones. Rio do Pasto red beds, with fossil reptiles (*Scaphonyx* and *Erythrosuchus*) and fossil trees.
Passa Dois Series:	Rocinha limestone. Estrada Nova gray and variegated shales with cherty concretions, and sandy beds. Iraty black shale, *Mesosaurus* and *Stereosternum*.
Tubarão Series:	Palermo shales. Rio Bonito shales and sandstones, with coal measures and Gangamopteris (Glossopteris) flora. Orleans conglomerate. [Glacial] Yellow sandstones and shales to granite floor.

SYNOPSIS OF THE PALEOBOTANICAL DATA

On the side of the fossil plants it will be possible to give in this place only an enumeration of the species, with references to their stratigraphical position in Brazil. For the descriptions and other taxonomic data relating to the species the reader is referred to the report of the commission. In the following list[2] the species characteristic of the Gondwana series in other continents are marked by an asterisk (*), those clearly representing Gondwana types but comprising forms previously unknown are designated by the double asterisk (**), those generally regarded as proper to the Permo-Carboniferous of the Northern Hemisphere by a dagger (†), while those of mixed distribution or of unascertained geographical significance are indicated by the double dagger (††).

Rosellinites Gangamopteridis D. W.**; Hysterites brasiliensis D. W.**; Equisetites calamitinoides D. W.††; Schizoneura ? sp.**; Phyllotheca Griesbachi

[1] *Science*, Vol. XXIV, No. 612, 1906, p. 377.

[2] *Reinshia australis* Bertr. & Ren. var. *brasiliensis*, which is included in the descriptive memoir, is here omitted, since from evidence kindly communicated by Dr. Derby it appears probable that the specimens in the Brazilian Exhibit at the St. Louis Exposition were first brought to Brazil from Australia.

Zeill.*; Phylotheca Muelleriana D. W.**; Phylotheca (?) sp.**; Lycopodiopsis Derbyi Ren.††; Lepidodendron Pedroanum (Carr.) Zeill.††; Lepidophloios laricinus Sternb.†; Sigillaria Brardii Brongn.†; Sigillaria austarlis D. W.††; Sigillaria sp.††; Sigillaria (?) muralis D. W.††; Sphenopteris hastata McCoy?*; Sphenopteris sp.**; Psaronius brasiliensis Brongn.**;[1] Neuropteridium Plantianum (Carr.) D. W.[1] (*N. validum*)*; Glossopteris Browniana Brongn.*; Glossopteris indica (Brongn.) Schimp.*; Glossopteris ampla Dana.*; Glossopteris occidentalis D. W.**; Glossopteris sp.**; Vertebraria sp.**; Gangamopteris obovata (Carr.) D. W.* (*G. cyclopteroides*); Ottokaria ovalis D. W.**; Arberia minasica D. W.**; Derbyella aurita D. W.**; Noeggerathiopsis Hislopi (Bunb.) Feist.*; Cardiocarpon Seixasi D. W.††; Cardiocarpon Moreiranum D. W.††; Cardiocarpon Oliveiranum D. W.††; Cardiocarpon Barcellosium D. W.††; Voltzia? sp.††; Dadoxylon Pedroi Zeill.††; Dadoxylon nummularium D. W.††; Dadoxylon meridionale D. W.††; Carpolithus? sp.††; Hastimima Whitei D. W.**

FLORAS AND THEIR CLIMATIC SIGNIFICANCE

The examination of the stratigraphical occurrence of the species just enumerated indicates that at the base of the Brazilian coal measures we have a Lower Gondwana flora essentially identical with that found in the corresponding beds in India, Australia, and South Africa; and that in the higher beds we have the introduction of Northern Permo-Carboniferous types which appear to indicate the progress of a great climatic change. The data bearing on this matter are briefly summarized in the following paragraphs:

Basal, Lower Gondwana Flora.—The only species collected from a shale lens but 6 meters above the unconformable crystalline floor of the coalfield is *Gangamopteris obovata* (*G. cyclopteroides*), one of the most characteristic as well as earliest of the Lower Gondwana plants.[2] The next higher plant bed of importance lies at a horizon but 55 meters above the granite floor near Minas, state of Santa Catharina, where we find, in the Minas formation, ***Rosellinites Gangamopteridis*, *Hysterites brasiliensis*, *Phyllotheca Griesbachi*, *Phyllotheca Muelleriana*, *Phyllotheca* sp., *Glossopteris Browniana*, *Vertebraria* ?, *Gangamopteris obovata*, *Arberia minasica*, *Derbyella aurita*,**

[1] Not represented in the collection.

[2] On account of its strictly Paleozoic distribution, wide geographical range, ready recognition, and pre-eminent characterization of the Lower Gondwana series GANGAMOPTERIS has been substituted by the writer for "*Glossopteris,*" previously used to designate the flora, but which is unsuited therefor on account of its transgression in the Mesozoic and its nomenclatorial inapplicability.

Noeggerathiopsis Hislopi, Cardiocarpon (*Samaropsis*) *Seixasi, Cardiocarpon Moreiranum, Voltzia* ? sp., and *Hastimima Whitei.*

The flora enumerated above belongs to the early typical GANGAMOPTERIS or Lower Gondwana flora. The distribution of its identical or related species in other continents indicates contemporaneity with the Ecca shales of South Africa, the upper coal measures of New South Wales, the upper marine coal measures of Tasmania, and the Karharbari beds of India. Concomitantly the underlying Orleans conglomerate of the Brazilian region is correlated with the Dwyka conglomerates of South Africa, the Baccus Marsh conglomerates and their equivalents in Australia and Tasmania, and the Talchir conglomerates of India.

Cold climate of the basal flora.—The appearance of the GANGAMOPTERIS flora in its simple and relatively pure condition immediately above the basal bowlder beds of South America in a way exactly similar to its occurrence in India, Africa, and Australia bears irrefragable evidence of a corresponding similarity of the accompanying climate. The consequent inference that glacial conditions had preceded the flora in South America is verified by Dr. I. C. White's studies of the basal bowlder beds and conglomerates of the Santa Catharina series in which he finds distinctly glaciated material. The earlier suggestion by Dr. Orville A. Derby[1] that the basal Permo-Carboniferous bowlder beds of Brazil were associated with glacial activity in that continent thus finds a double confirmation.[2] As to the reality of glacial action during Permo-Carboniferous time it may be added that, notwithstanding the great differences of opinion as to causes, the work of ice, especially in South Africa where the glaciation was on a truly great scale, has been so convincingly demonstrated over large areas as no longer to be questioned or require the citation of further proof.[3]

[1] *Waagen, Rec. Geol. Surv. India*, Vol. XXII, Pt. 2, 1889, p. 69.

[2] In this connection it may be of interest to note that identical conclusions as to Paleozoic glaciation in Brazil were reached by Dr. White and the writer, one on purely geological evidence, the other on strictly paleobotanical data, each entirely without knowledge of the facts or opinions of the other.

[3] See T. W. E. David, *Quarterly Journal of the Geological Society of London*, Vol. LII, 1896, p. 289; Wm. M. Davis, *Bulletin of the Geological Society of America*, Vol. XVII, 1906, p. 47; Frech, *Lethaea Palaeozoica*, Vol. II, Lief. 4, 1902, p. 572; and Chamberlin and Salisbury, *Geology*, Vol. II, 1906, p. 538.

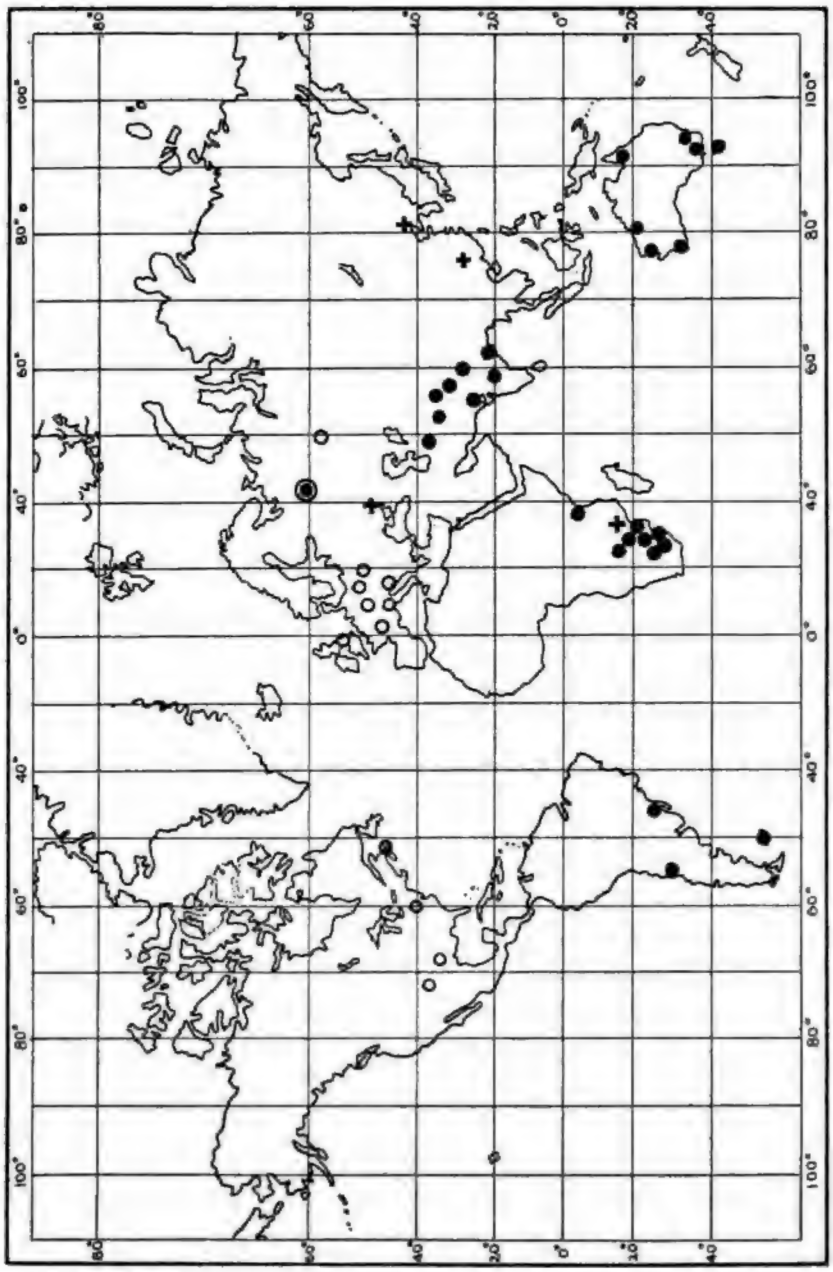


FIG. 1.—Regions in which the GANGAMOPTERIS flora has been found are shown by solid black rings. Several neighboring regions of our higher Coal Measures flora are shown by crosses. General regions of the Cosmopolitan Permian flora are indicated by white rings. The dark circle in the larger light ring designates mingling of Cosmopolitan and GANGAMOPTERIS types in the later Permian

The regional refrigeration which drove back or exterminated the Northern Permo-Carboniferous flora undoubtedly constituted the principal environmental cause in the development of the GANGAMOPTERIS flora. In the Greta series of New South Wales this flora appears to have been interglacial. The absence of cosmopolitan northern types, particularly of the Lycopods, from the beds immediately following the glacial conglomerates in Brazil, as well as in other areas of the pure GANGAMOPTERIS flora can have been due only to the inhospitability of the environment to those types at this time.

Beginning of return of northern types.—Although subsequent collections may show a lower range for some of the types, it would appear from the data at present available that in the Brazilian basins the first traces of Northern Permo-Carboniferous elements are met at 120 meters above the granite where we find Lepidophytic megaspores. At 135 meters above the granite—i. e., in the Nova Estrada formation—the same form of spores is mingled with cortical fragments and leaves of *Sigillaria*. With them are *Equisetites calamitinoides*, *Schizoneura* (?) sp., *Sigillaria australis*, *Sphenopteris hastata* (?), *Glossopteris indica*, *Glossopteris ampla*, *Glossopteris occidentalis*, *Noeggerathiopsis Hislopi*, and *Cardiocarpon Oliveiranum*. The flora as a whole is still overwhelmingly Southern, most of the species being characteristic of the older Gondwana series.

Continued climatic amelioration.—From a group of coals situated about 157 meters above the granite floor, and about 100 meters below the top of the Iraty black shale, which forms the base of the Passa Dois series, were collected *Lepidophloios laricinus*, *Glossopteris Browniana*, *Glossopteris indica*, *Glossopteris* sp., *Vertebraria* (?) sp., *Gangamopteris obovata*, *Noeggerathiopsis Hislopi*, *Cardiocarpon Moreiranum* and *Cardiocarpon Barcellosi*, while a carbonaceous stratum a little higher is largely composed of the remains of *Lepidodendron Pedroanum*, *Lepidophloios laricinus* and *Sigillaria Brardii*. The collections from these horizons are quite small and insufficient in species; but they are ample enough to show conclusively the presence of Lepidophytic elements typical of the Northern Permo-Carboniferous flora mingling with the GANGAMOPTERIS flora. It is interesting to note that at the level of the last-mentioned coal the Lycopods again establish their pre-eminent part as great coal-makers.

The climatic cycle.—So far as is known the floras preceding the period of Permo-carboniferous glaciation in India, Australia, South Africa, and South America were essentially identical with those of the northern hemisphere. The phytiferous strata as yet brought to light show the presence of the cosmopolitan or northern Lower Carboniferous flora in Argentina and Australia, of a Middle Coal Measures flora in the Heraclea basin in Asia Minor, and of a Stephanian flora (probably Upper Conemaugh or Monongahela in age), in the vicinity of Tete, on the Zambesi, in what was later the territory of the GANGAMOPTERIS flora in South Africa. The extermination of the northern, or cosmopolitan flora from the regions of the pure GANGAMOPTERIS flora can have been due only to the causes producing the glacial refrigeration and the GANGAMOPTERIS flora itself in those portions of the earth. The presence of a Sigillaria in the Ecca beds of South Africa, and the invasion by the above-named Lepidophytes in Brazil shows at once not only an amelioration of the climate sufficient for the return of some of the northern elements, but also that the extent of the land areas was such as to make their return possible. In fact, it is probable that no oceanic barrier existed to prevent free access of the northern types at any time during the period of cold. It is important to note that these hardy invaders from the northern flora which, under the influence of ameliorating climatic conditions were the first able to regain a foothold in the lost territory, belonged to the Lepidophytes, or Lycopodineous group.

It thus appears that in South America, as in South Africa, the Lepidophytes were the first to mingle with the flora which succeeded the glacial climate, the invaders being apparently in greater force in South America.[1] The greater variety as well as the far greater numerical representation of the Northern Lycopod elements in the Brazilian area may be due either to relative nearness to the border of

[1] Bodenbender reports the presence of *Lepidophloios laricinus, Sigillaria Brardii, Pachypteris*, and *Walchia* in Argentina. As to *Cardiopteris polymorpha, Adiantites antiquus*, and *Rachopteris* (Lower Carboniferous types), and *Lepidodendron selaginoides, L. aculeatum*, and *L. Veltheimianum* (Lower coal measures species) also reported by him there is room for doubt concerning either the identity of the plants or their relations to the GANGAMOPTERIS flora. See *Bol. Acad. Nac. Ciencias, Cordoba*, Vol. XVII, 1902, p. 203.

the refrigerated area, or to a more rapid and well-marked moderation of the climate.

Evidence of equable climate during Passa Dois deposition.—The fossil-plant material collected from higher horizons of the Brazilian coal measures unfortunately consists only of fossil stems; but these furnish almost unmistakable evidence of a mild and equable climate. From beds near the top of the Tubarão series, in Rio Grande do Sul, not far above the horizon last mentioned a gymnospermous type, *Dadoxylon* (?) *meridionale*, was collected. Another horizon somewhat higher, or about 75 meters above the base of the Passa Dois series, in the same state, furnished *Dadoxylon* (?) *nummularium* and a tree Lycopod of large size, *Sigillaria* (?) *muralis*. Still another fossil Lepidophyte, *Lycopodiopsis Derbyi*, was found at 155 meters above the Iraty black shale in the state of São Paulo. The Iraty black shale, which has been definitely traced by Dr. White throughout the region, is probably the source of the *Dadoxylon* (?) *Pedroi* Zeill., and of Brongniart's *Psaronius brasiliensis*. It is also the horizon of Cope's *Stereosternum tumidum* as well as of the *Mesosaurus brasiliensis* McGregor, collected by Dr. White.

Even more importantly significant than the presence of the arborescent Lycopods, from the climatic standpoint, is the complete or almost total absence from the various fossil woods of all trace of annual rings. On the other hand annual rings are conspicuously developed in the trees described by Arber[1] and Shirley[2] and found associated with the pure GANGAMOPTERIS flora in beds overlying the glacial conglomerates in New South Wales and Queensland. The sensible abatement of climatic rigor indicated by the appearance of the Lycopods in the upper part of the Tubarão series in Brazil is thus confirmed by the uninterrupted growth in the fossil trees from the still higher beds, during whose deposition there appear to have been no marked seasonal changes of climate. The presence of the large Lycopods and of the Psaronius trunk in the Passa Dois series warrants the expectation that further search will reveal a pteridophytic and gymnospermous flora closely related to the contemporaneous

[1] *Catalogue of the Fossil Plants of the Glossopteris Flora in the Department of Geology, British Museum*, 1905, p. 191.

[2] *Geol. Surv., Queensland*, Bull. No. 7, 1898, p. 14.

Northern Permian flora[1] and perhaps grown under climatic conditions but little dissimilar to those prevailing to the northward.

The large tree Lycopods and the Psaronius are sufficient evidence of the Paleozoic age of the environing rocks, and, therefore, of the greater part of the Passa Dois series. Likewise the occurrence of *Lycopodiopsis Derbyi* at the much higher horizon furnishes good ground for anticipating that the upper part also of the series will fall within the Permian limits. But the presence in the Rio do Pasto beds of Erythrosuchus and of *Scaphonyx Fischeri*, regarded as closely related to Euskelesaurus, of the Stormberg beds in South Africa, argues for the Triassic age of the red beds and eruptives of the succeeding São Bento series.

SUMMARY OF THE CLIMATIC CHANGES

Briefly summarized, the paleobotanical evidence now in hand, though very incomplete, goes to show:

1. The occurrence of the cosmopolitan or world-wide floras in various parts of the southern land areas up to a point somewhere in the Upper Coal Measures or upper Stephanian; and, consequently, a corresponding uniformity or equability of climate in both the northern and southern regions.

2. The presence, at the base of the Brazilian coal measures, of a pure GANGAMOPTERIS flora essentially identical with that found in beds following the glacial deposits of India, Australia, and South Africa, and undoubtedly existent under approximately identical climatic conditions.

3. Some moderation of the climate at an early date so as to permit the immigration of a few of the hardier Lycopodineous types from the contemporaneous Northern or "cosmopolitan" Permo-Carboniferous flora.

4. The restoration of an equable Permian climate in southern South America permitting the invasion of other Northern pteridophytic types and the growth of gymnospermous trees without annual rings.[2]

[1] The Psaronius perhaps belongs to the Cladophleboid group of Pecopterids.

[2] The close of the Permian in the Brazilian basins appears to have been marked by deposition of variegated shales and cherts indicating oxidization and probable retreat of the sea, comparable to the geological phenomena of the time in other parts of the world.

The period from the deposition of the lowest coals overlying the glacial bowlder material to the return of the Lepidophytes is believed by the writer to have been not long.[1] It seems probable that the return of an equable climate was as early as the beginning of the Damuda Series of the Gondwana System, or as the early Zechstein (Upper Permian) of the northern system.

THE GANGAMOPTERIS PROVINCE

The GANGAMOPTERIS flora appears to have flourished in a state of relative purity in the Permo-Carboniferous coalfields of India; in Queensland, New South Wales, Victoria, and Tasmania, in the Australian region; in German and Portuguese East Africa, Portuguese South-East Africa, Rhodesia, Zululand, the Transvaal, the Orange River Colony, Natal and Cape Colony in South Africa; and in Argentina and southern Brazil in South America. It appears to be present, perhaps in a less pure condition, in Kashmir, Afghanistan, and Persia, while a number of its characteristic elements mingled with northern types are found in the Upper Permian (Zechstein) of northern Russia and in the Altai Mountains. The territory of the pure or typical GANGAMOPTERIS flora may be termed the GANGAMOPTERIS Province. It conforms for the most part to the geographical, though not the geological, limits of the "Glossopteris Province" as the latter was proposed and defined by Professor Zeiller.[2]

The GANGAMOPTERIS or "Gondwana-land" continent.—The GANGAMOPTERIS flora is predominantly a terrestrial flora of somewhat highly varied composition. Hence the occurrence of this flora in great uniformity, including an extraordinarily high degree of specific identity, and in relative purity, contemporaneously in India,

[1] In Australia the more rigorous climate seems to have prevailed longer, with greater deposition of coal measures and with recurrence of glaciation. The Brazilian records may pertain only to the later of the ice extensions, or, on the other hand, regional subsidence or other related causes may sooner have brought amelioration in this quarter of the globe.

[2] *Rev. gén. d. science*, 8ᵉ *année*, 1907, p. 5. The GANGAMOPTERIS province embraces the regional distribution of the original or typical flora, while at the same time concerning only beds of Paleozoic age, thus escaping the regions of Mesozoic migration and mingling of the genus *Glossopteris* and several of its early associates with the northern post-Paleozoic flora. The genus Gangamopteris appears not to have survived the Permian.

Australia, South Africa, and southern South America, leaves no recourse but to conclude that the land surfaces over which it extended were in such continuity, or intimate geographical relation, as freely to permit the migration of the flora, practically *in toto*, between all these quarters of the globe.

The regions in which remains of the GANGAMOPTERIS flora have already been brought to light, are roughly indicated on the accompanying map, Fig. 1. The disposition of these areas, chiefly in the Southern Hemisphere, and their geographical relations to the present Antarctica, point strongly to the inclusion of the latter as an important part of a great continent or aggregate of very closely proximate land masses freely traversed by the GANGAMOPTERIS flora. A relationship of the Antarctic lands to the southern continents is still indicated to a certain extent by the submarine topography. Their efficiency as a bridge in Permian time is almost beyond question; and it is, perhaps, reasonable to assume that they are parts of a great continental aggregation, essentially constituting, in a broad sense, a greater "Gondwana-land," of which Australia and southern South America were perhaps but lobes.

At this great length of time, since the Paleozoic, and under the conditions of lack of Antarctic geological information a delineation of southern continental outlines is largely mere guesswork. It does not appear to the writer as necessary or even justifiable greatly to interfere with the main basins of the south Atlantic Ocean or seriously to threaten the existence of the Indian Ocean. The oceanic displacements involved in postulating so great southern land masses would seem to be in part compensated by the smaller proportions of the Permian land areas not only in South America, but in the other continents.

The continued efficiency of the Antarctic land connection in Mesozoic time is attested by the relations of both land plants and vertebrates in the Southern Hemisphere. As bearing distinctly on this subject from the paleobotanical standpoint one need cite only the occurrence of the Rajmahal flora in Argentina as reported by Professor Kurtz.[1] The great extent of the land surfaces, whether com-

[1] The intimate relationships of the Mesozoic and even of the Tertiary vertebrates of Patagonia to those of the eastern hemisphere have been abundantly shown by Professors Ameghino and Scott.

bined in a single continent or included in several very closely situated land masses comprising the greater "Gondwana-land" of Permian time is also indicated by the vast areas of freshwater sediments unconformably laid down in the Indian, South African, and South American regions.

AGE OF THE GANGAMOPTERIS FLORA

It has been shown that the GANGAMOPTERIS or Lower Gondwana flora dates from the time of the glacial bowlder conglomerates—i. e., from the glacial period itself. Though many geologists and paleontologists appear still to disagree as to the geological time of this date, the criteria are sufficient to fix it within very close limits. The refrigeration cannot have antedated the flora at Tete[1] on the Zambesi, which is of middle or lower Stephanian age. So also the very late Coal Measures plants from the province of Shansi in China[2] and the flora representing a horizon close to the base of the Permian at Jantai in Manchooria[3] show no important climatic differences from the topmost Carboniferous floras of western Europe. On the other hand the mingling of GANGAMOPTERIS and Glossopteris species with *Callipteris*, *Lepidodendron*, and Zechstein animal remains in northern Russia[4] show that the flora was well established and becoming enriched at that time. The invertebrate fauna of the marine beds associated with the conglomerates in New South Wales are regarded by Frech[5] as Permian. The introduction of Lepidodendron, Lepidophloios, and Sphenophyllum in the GANGAMOPTERIS flora probably occurred before the close of the Rothliegende. It becomes most highly probable, therefore, that the refrigeration attending the birth of the flora was consequent to the great terrestrial uplift and withdrawal of the sea at the close of the Carboniferous or at the beginning of the Permian. The flora may accordingly be regarded as dating from the close of the former. The approximate equivalences of the formations, so far as recognized, in the at present detached areas of

[1] Zeiller, *Ann. d. Mines* (2) Mem. Vol. IV, 1883, p. 594.

[2] Schenck, in Von Richthofen: *China*, Vol. IV, 1883, p. 209. Also Abbado, *Pal. Italica*, Vol. V, 1900, p. 125.

[3] Zalessky, *Verh. k. min. gesell.*, St. Petersb. (2), Vol. XLII, 1905, p. 385.

[4] Amalitzsky, *Comptes Rendus*, Vol. CXXXII, 1901, p. 591.

[5] *Lethaea palaeozoica*, Vol. II, Lief. 4, 1892, p. 590.

PERMO-CARBONIFEROUS FORMATIONS OF THE GANGAMOPTERIS PROVINCE

		India	Queensland	N. S. Wales	Victoria	Tasmania	S. Africa	Argentina	Brazil
Mesozoic	Cosmopolitan Flora	Umia Jabalpur Kota-Maleri Rajmahal	Ippswich	Up. Clarence Hawksbury (glacial)	Bellarine Coals	Upper Jerusalem	Cave ss. Red beds		São Bento Serra Geral Botucatú
		Panchet	Burrum c.	L. Clarence			Stormberg	Cacheuta	R. do Pasto
Up. Permian	Gangamopteris Flora	Damuda Raniganj Barakar	Bowen River Coals	Ballimore and Newcastle coal series	Baccus Marsh Series	Mersey and Porters Hill	Beaufort series	Red beds and sandstones	Passa Dois s. Rocinha ls. Gray & variegated sh. and ss. Iraty shale
L. Permian		Karharbari		Upp. Marine (glacial)			Ecca	Coals and shales	Tubarão Series Estrado N. Minas ss.
		Talchir (glacial)	Bowen R. Marine (glacial)	Greta coals L. Marine (glacial)	Baccus M. Conglomerate (glacial)	Upp. Marine with coals (glacial)	Dwyka conglomerate (glacial)	Basal conglomerate (glacial)	Orleans cgl. (glacial) ss. and sh. (local)
Pre-Permian	Cosmopolitan Flora	Unconformity	Unconformity	L. Marine Unconformity	Unconformity	Marine Unconformity	Unconformity Tete Stephanian Unconformity ?	Unconformity	Unconformity
			L. Carboniferous Devonian	L. Carboniferous Devonian	L. Carboniferous Devonian		Witteburg Devonian	Retamito Devonian	Granites and Devonian

the GANGAMOPTERIS flora are indicated in the accompanying table. No attempt is therein made to include or show the equivalents of all the Mesozoic formations.

ORIGIN OF THE GANGAMOPTERIS FLORA

The types composing the GANGAMOPTERIS flora belong, as Professor Arber[1] has so well shown, almost exclusively to families already well known in the cosmopolitan flora. They constitute genera or species more or less closely bound to their northern relatives, though often differing much in form and aspect. In general they appear simpler in figure, with a tendency to thickness and rugosity of leaf that may indicate either a xerophytic or pseudoxerophytic condition. On the whole the aspect of the plants distinctly suggests environmental conditions unfavorable to luxuriant plant growth. That the development of this flora was directly consequent to a Permo-Carboniferous period of regional refrigeration is now no longer questioned. In its purest and simplest composition, and with remarkable uniformity, it is found in India, Austraila, South Africa, and South America immediately above apparently contemporaneous formations bearing evidence of the work of ice. The conditions which brought the new flora into being banished or exterminated the Cosmopolitan or northern Permo-Carboniferous flora from the GANGAMOPTERIS province. The early return of a few of the hardier Lycopodineous forms in Argentina, Brazil, and South Africa, has already been mentioned. Most of the former plant population of the province died in exile, and only their posterity, especially among the Cladophleboid ferns and the Araucarian, Ginkgoalean and Cycadalean gymnosperms were able to traverse the lost territory and contest the GANGAMOPTERIS occupation.

It is not probable that any serious hindrance other than altitude or climate seriously opposed the return of the northern flora to the GANGAMOPTERIS province in either the Western or the Eastern Hemisphere. The early return of certain Lepidophytes to the Brazilian and South African regions and the invasion of the Russian area by some of the older Gondwana elements is evidence of the efficiency of

[1] *Catalogue of the Foss. Pl. of the Glossopteris Flora in the Department of Geology in the British Museum*, 1905, p. xx.

the land route. The absence of the northern flora from the series above the glacial deposits can therefore be due only to the uncongeniality of the province to that flora.

CAUSES OF THE PERMO-CARBONIFEROUS GLACIATION

So varied as well as great are the geological changes since Paleozoic time that the exposure, at this late date, of an ancient glaciated floor at even a few points is fortuitous. Yet proofs of Permo-Carboniferous land ice movement have been observed over an area more than 800 miles in length and 400 miles in breadth in South Africa,[1] while glaciated material is seen here and there over a very much larger territory. In Victoria the till and bowlder beds compose the greater part of a section about 1,700 feet in thickness. Bedrock striation, the work of grounded icebergs, if not of subaerial ice, is seen in India, and several provinces of Australia as well as in Tasmania. The GANGAMOPTERIS province undoubtedly witnessed Permo-Carboniferous glacial action many times greater than that which occurred in the Northern Hemisphere during Pleistocene time.

However complete the unanimity as to the fact of Permo-Carboniferous glaciation in the GANGAMOPTERIS province, there is little agreement as to the causes of that remarkable episode. The information obtained from South America both extends and defines more clearly the problem, though in the solution of the latter the testimony of the new data is perhaps chiefly negative.

So long as the glaciation was supposed to have been confined to the Indo-Africo-Australian quarter of the earth a shifting of the axis so as to place the pole in the Indian Ocean was urged in explanation of the regional refrigeration. The recognition of the glaciation in South America and as far north as latitude 28° in that continent seriously modifies if it does not completely destroy this hypothesis.

Depletion of atmospheric carbonic-acid gas.—Of the other hypotheses that which seems by far most nearly to meet the situation has for its essential condition loss of heat on account of a depletion of the atmosphere in carbonic dioxide consequent to great coal and limestone deposition during the Carboniferous epoch. Co-operative and

[1] Wm. M. Davis, *Bulletin of the Geological Society of America*, Vol. XVII, 1906, p. 377.

almost co-ordinate with this atmospheric impoverishment were, in the judgment of the writer, the size and height of the glaciated land masses.

That there was a change in the composition of the atmosphere toward the close of the Carboniferous is now generally admitted. Whatever may have been the effect of the limestone deposition, it is certain that the carbon extracted from air and sea and stored away in the coals and bituminous shales of the Paleozoic Coal Measures was far greater in amount than that in any other similar series laid down during geological time. Abundant red beds and oxidation bear evidence of the concomitant high proportion of oxygen in the atmosphere and of rapid evaporation.

Great extent of southern lands.—Concerning the size of the land masses the testimony is hardly less clear. It has been shown that the conditions of land plant and land vertebrate distribution call for the extension of land surfaces in one continuous or in several nearly contiguous continents including large portions of India, Australia, New Zealand, South Africa, and southern South America. It is probable that this connection was accomplished through the medium of an Antarctic continent, of which Australia, South Africa and a part of South America were possibly but lobes. The surviving or vestigial areas preserved in India, Africa, and South America bear evidence of the existence of enormous drainage surfaces on which the great series[1] of conglomerates and coal measures of the Gondwanas in India, the Dwyka and Ecca series in South Africa, and the Permo-Carboniferous of many states in Argentina and Brazil were laid down as fresh-water formations. The magnitude of the land ice action itself argues for extensive land surfaces in those regions.

Problem of tropical glaciation.—The most difficult feature of the problem relates to the geographical distribution of the glacial evidence. In India distinct ice work is found at 18° N.—i. e., within the tropics—and bowlders regarded as glacial have been found at 32° N., in the Salt Range. The Australian region within which glacial material is found extends from 20° 30′ S. to 42° S., and ranges

[1] In South Africa 4,000 feet; about 10,000 feet in New South Wales; 1,200 feet of the Talchic conglomerate, while the Damuda series alone is said to measure 10,000 feet in India.

through about 35° of longitude. In South Africa glacial material has been found from 25° to 33° S. and through 11° east and west, while in South America it appears to occur as far north as 30° S. In Australia there is proof of a recurrence of glaciation with a thin interglacial series (Greta), 230 feet in thickness including coals, between the bowlder beds.

Exaggerated temperature effects of elevation.—The occurrence of glacial phenomena within the tropics was presumably due in part to an extension of the southern cold with the favoring assistance of ocean currents and perpetual atmospheric "lows," resulting in part from continental relations and topography. The writer is strongly disposed further to attribute a very important part in the refrigeration, and more particularly the singular localization of the latter, to the height of the land on which the glaciers developed. Mention has already been made of the fact that the great coal measures series of the Gondwanas, of South Africa, and of South America are vast fluviatile or lacustrine deposits many thousands of feet in thickness, resting unconformably on old erosion basin floors. The enormous accumulations of coarse conglomeratic material in the eastern regions testify to the steep gradient of the drainage systems. The presence in nearly all regions of the great unconformity is itself evidence of the vigor of the post-Carboniferous uplift in the GANGAMOPTERIS province. In Africa and South America, at least, large portions of the land masses probably stood at a considerable elevation during glaciation. It is not clear that in Australia or India the source of the ice was near sea level, though on both the latter there is abundant evidence of the deposition of bowlders dropped from floating ice. Currents of cold water sweeping along the Antarctic continent may well have carried icebergs for long distances to the north in the Australian region.

A relatively high altitude for the areas of ice accumulation would not only enormously assist in explaining the peculiar geographical distribution of the ice phenomena, but it would seem to offer a satisfactory accounting for the differences in climate, as indicated by the floras, between the Northern and Southern regions. It has been urged by Chamberlin[1] that a diminution of the CO_2 of the atmosphere, with

[1] *Journal of Geology*, Vol. VII, 1899, pp. 545, 667, 751.

its attending decrease of humidity, would result in a marked increase in the difference between the mean temperatures of land and sea, the loss of the sun's heat by the land being greatly accelerated as compared to the lesser loss by the sea; so that despite stronger winds, convection currents, etc., an increasing cold would prevail in the greal land areas. If to this principle is added a most important fact, that altitudinal differences in temperature would be exaggerated if the carbon-oxide of the atmosphere were reduced, it will appear probable that partial depletion of the carbonic acid gas might produce greatly magnified effects of cold, with accentuated seasonal differences at relatively moderate elevations in the interiors of the land masses,[1] while the climate near sea level especially in the smaller lands or in proximity to large oceanic bodies, might still be mild and relatively equable. It might thus be possible for the Cosmopolitan flora to survive on the low or base-leveled coasts of the sea-girted northern lands while glacial conditions prevailed at no great elevation in the interior plateaus and subaerial basins of the Southern "Gondwana-land." The writer is therefore disposed to believe that the glaciation in the GANGAMOPTERIS province was secondarily due to the elevation of its land masses to greatly reduced refrigerative altitudes at the time of the post-Carboniferous uplift. The elevation of the southern land masses and their erosion and glaciation are fully demonstrated. The enormous thickness of continental sediments already noted in Africa, India, and Australia, including over 1,200 feet of basal conglomerates alone, is itself evidence of a considerable height of land. In Australia there was probable oscillation and recurrence of glaciation as shown by the intercalation of the Greta coals and shales, the latter inclosing the pure GANGAMOPTERIS flora.

[1] The accelerated decrease of temperature in ascending the atmospheric column occasioned by reduction of CO_2 is remarked by Chamberlin. Granting that carbonic acid gas in the atmosphere exerts the influence in arresting the outgoing heat rays attributed to it by Arrhenius and Chamberlin, it is plain that, on account of the extension of its zone far above that of the humidity, an increase or reduction of its volume must also directly and strongly affect the differences in temperature due to differences of altitude. With reference to the climatic effects of changes in the proportion of CO_2 in the atmosphere, the reader is referred to the most valuable discussion published by Professor Chamberlin in Vol. VII of the *Journal of Geology*, 1899, or the second volume of the *Geology* published (1906) by that author in collaboration with Professor R. D. Salisbury.

SURVIVAL OF NORTHERN, "COSMOPOLITAN," TYPES

The survival, in the northern province, of the Cosmopolitan, Carboniferous flora, which had been exterminated from the greater part, at least, of the GANGAMOPTERIS province, and its metamorphism to the Cosmopolitan Permian flora, was presumably due to the generally low base-leveled state of the northern lands and the growth of the plants near tide level in regions bordering great bodies of water. The greater retention of the sun's heat by the sea and the greater humidity would co-operate with the low altitudes to neutralize the effects of atmospheric carbonic acid reduction. The contrast with the climate of the basins in the interior of the more elevated GANGAMOPTERIS (Antarctic) continent could not fail to be great. It is worthy of note in this connection that in general the floral changes in passing to the Permian are least marked, the number of surviving later Carboniferous species being greatest, in those northern regions in which the post-Carboniferous uplift was least and there was less withdrawal of the sea. The best-marked illustration of this is furnished by the Appalachian trough in which the floral change is relatively gradual, the more characteristic Permian species being probably migrant from some more strongly affected region. The early moderation of the climate in Brazil so as to permit the return of a few hardy northern types and the enlargement of the GANGAMOPTERIS flora in other regions by the mingling of northern derivatives were presumably due to subsidence under loading of the basins; the general extension of the marine surface in the upper Permian; and, possibly, to a direct carbonic acid contribution attending the great vulcanism of the Permian.

The flora of the Upper Permian is known in but few parts of the earth, but it is found that early in the Zechstein GANGAMOPTERIS and northern Permian elements mingled in the basins of northern Russia and the Altai; the northern Cycad, Pecopteroid, and Coniferous elements had already invaded the GANGAMOPTERIS province, and from this mingling was developed a group which survived as the nucleus of a new world-wide Cosmopolitan flora, that of the Older Mesozoic.

STRATIGRAPHIC RESULTS OF A RECONNAISSANCE IN WESTERN COLORADO AND EASTERN UTAH[1]

WHITMAN CROSS

One of the principal features of interest in the study of the sedimentary formations of the western mountain slopes of Colorado is their correlation with the formations of the Plateau Province to the west. I have already introduced the discussion of this subject in an article on the Red Beds of Colorado (**8**)[2], but without first-hand information as to the Plateau country. I am now able to review and affirm the correlation there suggested, on the basis of observations made during the summer of 1905, in the course of a reconnaissance from Mancos, on the southwestern flank of the San Juan Mountains, in Colorado, to the vicinity of Moab, on Grand River, in Utah, returning to the northern slope of the San Juan at Montrose. Other members of the party engaged in this reconnaissance were Messrs. L. H. Woolsey, W. H. Emmons, and Geo. F. Kay, all of whom had seen, or were to see later in the season, the stratigraphic succession of formations in the San Juan region. I wish to acknowledge my indebtedness to all these gentlemen for observations recorded with my own in the following pages.

Itinerary.—The party proceeded west from Mancos to Cortez, in the Montezuma Valley; thence northwesterly across the headwaters of various branches of Montezuma Creek to the northeast base of the Abajo or Blue Mountains, in Utah. From this point the route northward lay mainly in Dry Valley which extends nearly to the La Sal Mountains. This part of the journey was near the line followed by Newberry in 1859 (**28**). Turning westward down Spanish Valley to Moab, extensive sections were examined on both sides of Grand River. From Moab we proceeded up the Canyon of Grand River, some 20 miles, and then turned east, passing over the northern slopes of the La Sal Mountains, and thence south through Sindbad and

[1] Published by permission of the Director, U. S. Geological Survey.

[2] Numbers in parentheses refer to the bibliographic list at the end of this paper.

Paradox Valleys. The Dolores River was crossed in Paradox Valley and from that point the route turned again northward following the crest of Uncompahgre Plateau to Unaweep Canyon, the remarkable transverse gorge examined by Peale (**29**). The section exposed in West Creek near Dolores River was studied in some detail. From Unaweep Canyon we retraced our course along the Uncompahgre Plateau and passed down its eastern slope to Montrose. During this journey, of about 450 miles, occupying 30 days, excellent opportunities were presented for observing the stratigraphic relations of formations ranging from the Pennsylvania Carboniferous to the Mancos shale of the Cretaceous.

It will be a great aid to the reader in comprehending the significance of the recorded observations if he will refer to Sheets XIV and XV of the Hayden *Atlas of Colorado* and adjacent parts of Utah, which represent the whole of the area traversed, with the exception of the vicinity of Moab.

GENERAL CORRELATION OF FORMATIONS

The plan of presentation will be to take up the formations of each system in turn and give the evidence which identifies the stratigraphic units adopted in the Colorado folios with certain ones found in the Plateau region, with suggestions, more or less definite as the case may be, as to correlation with the terminology of Peale, Holmes, and other geologists who have written upon the region visited. The table of correlation appearing on the following page is presented as a guide in following the discussion.

CRETACEOUS FORMATIONS

The floor of the main plain or plateau between the San Juan Mountains and Grand River Canyon in Utah, variously designated on the Hayden maps, in adjacent areas, as San Miguel Plateau, Dolores Plateau, and Great Sage Plain, is immediately underlain by the Dakota sandstone. Speaking of the very district traversed by our party on the outward journey, Holmes remarks that "over hundreds of square miles these sandstones lie comparatively unbroken, while the loose series of shales above have been swept off like so much dust from a great floor" (**17**, p. 259).

CORRELATION OF FORMATIONS

<table>
<tr><th colspan="3">San Juan Folios, U. S. G. S.</th><th>Peale</th><th>Holmes</th><th>Powell</th></tr>
<tr><td rowspan="2">Cretaceous</td><td colspan="2">Mancos</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Dakota</td><td>Dakota or Upper Dakota</td><td>Upper Dakota</td><td>Henry's Fork</td></tr>
<tr><td rowspan="3">Jurassic</td><td rowspan="3">Gunnison</td><td rowspan="2">McElmo</td><td>Lower Dakota</td><td rowspan="2">Lower Dakota</td><td rowspan="2">Flaming Gorge</td></tr>
<tr><td>Jurassic</td></tr>
<tr><td>La Plata</td><td rowspan="2">Triassic</td><td rowspan="2">Triassic</td><td>White Cliff</td></tr>
<tr><td>Triassic</td><td colspan="2">Dolores</td><td>Vermilion Cliff</td></tr>
<tr><td rowspan="2">Carbon-
iferous</td><td>Permian ?</td><td>Cutler</td><td>Permean
Permo-Carbonifer-
ous, or Upper
Carboniferous</td><td rowspan="2"></td><td>Shinarump Group
(All assigned to
Triassic)</td></tr>
<tr><td>Pennsyl-
vanian</td><td>Hermosa</td><td>Middle Upper
Carboniferous</td><td>Aubrey</td></tr>
</table>

The continuity of exposures, the persistence of lithologic characters, and the simplicity of stratigraphic relations place it beyond question that the section under discussion has for its upper members the Dakota sandstone and a variable remnant of Cretaceous shales, everywhere of the same general characteristics. The shale formation has been named after the town and valley of Mancos, our starting point, and I am aware of no reason why that name should not apply to the portions of that formation remaining above the Dakota, over the entire Plateau Province east of the Colorado and Grand Rivers, if not, indeed, still farther westward.

The formation here called Dakota is that designated as "Upper Dakota" on Sheets XIV and XV of the Hayden *Atlas of Colorado*, covering the portion of Colorado and Utah with which this discussion has to do. The "Lower Dakota" of those maps was a division established by Holmes for strata below the commonly recognized Dakota, as will shortly be explained.

While this reconnaissance was in progress Stanton and others were demonstrating that the beds hitherto referred to the Dakota to the east of the mountains, in the Arkansas Valley, were in part of the Comanche or Lower Cretaceous Series (**36**). Our observations were not directed to this point, but a re-examination in 1906 of the Dakota on the south flank of the San Juan failed to reveal ground for assigning any part of the formation called the Dakota in the San Juan folios to the Comanche Series.

JURASSIC FORMATIONS

All geologists who have examined the Mesozoic section of western Colorado have been impressed with the strong lithologic resemblance exhibited by several hundred feet of strata, occurring immediately below the Dakota to the fresh-water Jurassic beds found along the eastern base of the Front Range and characterized by the wonderful Dinosaurian fauna exploited by Marsh and others. With one exception, to be considered below, this lithologic similarity and corresponding stratigraphic position have been considered sufficient to warrant the assignment of the western slope beds to the Jurassic.

The first to give a formation name to those strata was Eldridge (**13**), who called them the Gunnison formation. In the San Juan region it was found better to divide the Gunnison into the McElmo and La Plata formations, the former to include the alternating sandstones and variously colored marls and shales of the upper part of the section, and the latter the heavy sandstones of the lower portion.

THE McELMO FORMATION

Before the McElmo beds were so named (**3**) they had been studied in the Telluride quadrangle at the head of San Miguel and Dolores Valley, and had been traced for some distance down each stream.

They are continuously exposed down the canyon of the former to the Dolores River and have a wide distribution in the Uncompahgre Plateau, about the La Sal Mountains and in the lower Dolores and the Grand River valleys. This is clearly stated by Peale in the *Report* for 1875 (**29**). But the Hayden map covering the area just mentioned shows "Lower Dakota" beds as present beneath the plateau-making Dakota proper, and in Peale's *Report* for 1876 (**30**) he divides the

beds formerly called Jurassic into "Lower Dakota" and Jurassic, consistent with the map. It may be well to make a summary statement in this place concerning the origin and application of the term "Lower Dakota," since the use of the Hayden map is rather confusing without explanation. Moreover, the McElmo beds were named from a locality where the Hayden map shows no Jurassic beds.

While surveying the Rico quadrangle the Dakota and subjacent strata were traced southwesterly down the Dolores Valley to the great bend of the river, where it turns due north. But a few miles west of that point several branches of McElmo Creek, a large tributary of San Juan River, cut below the Dakota sandstone into the underlying Jurassic beds. Flowing at first in narrow canyons rimmed by the Dakota, these various forks finally widen into valleys presenting broad exposures of the strata in question. In 1897, H. S. Gane, who had been my assistant in the Telluride quadrangle work, traversed the main McElmo Valley from its head to the San Juan River and upon his report the name McElmo was chosen for the Jurassic formation beneath the Dakota.

The Hayden map, Sheet XV of the *Atlas of Colorado*, represents the "Lower Dakota" as the principal formation below the plateau sandstone, in McElmo and Montezuma Valleys and in the adjacent portion of the broad San Juan Valley. Apparently the "Lower Dakota" of that map represents in fact the general distribution of the McElmo formation. No Jurassic formation is shown upon the Hayden map of that region.

This cartographic representation is based on the work of W. H. Holmes, and its explanation is to be found in his report for 1875 (**17**, p. 260). Describing in general terms the section below the Dakota proper Holmes says "The variegated series which succeeds it [downward] I at first felt inclined to call Jurassic, since it resembles so closely the variegated beds that on the eastern slope of the mountains have usually been credited to that age." After mentioning details of differences in lithologic character, Holmes refers to a much more important basis for his conclusion. He states (**17**, p. 261) that: "In Middle Western Colorado Dr. Peale has found Cretaceous fossils in a stratum of sandstone some three or four hundred feet beneath the bed of conglomerate [referring to the basal Dakota conglomerate],

and also beneath a series of variegated beds that resemble these in this section." No mention of even the general character of these fossils is made, nor can I find any further reference to them in the publications of the Hayden Survey. Personal inquiry of both Messrs. Holmes and Peale brings out the fact that after the lapse of many years spent in other lines of work, neither geologist is able to recall the basis for the statement that such fossils had been discovered, nor can records in regard to them be found. As the observations of the last 30 years do not indicate the existence of Cretaceous fossils in the position referred to, it must be assumed that the statement is an error, the origin of which cannot now be fixed.

The McElmo beds in characteristic development were seen by us in Dry Valley and on the eastern flanks of La Sal Mountains, in Dolores Valley, and in many places on Uncompahgre Plateau, as far north as Unaweep Canyon. To the north from that locality Peale refers to the formation as maintaining the same general character. No representative of the Marine Jurassic reported by Powell (**33**) and others from Utah was observed by us.

Rumors of large bones, presumably in the McElmo beds, have come to my attention several times in recent years, but never with exact locality named, and no trace of such remains has been found in the San Juan region.

The McElmo beds of Dry Valley are fossiliferous, locally, at least, as proven by Newberry, who found saurian bones in place at about 500 feet below the Dakota (**28**, p. 91), in the southeastern branch of Dry Valley, named by him Cañon Pintado or Painted Cañon. From Newberry's description of the locality and our own observations of the Cañon Pintado from the mesa to the west, as well as on the route traversed through Dry Valley, it is certain that the saurian bones came from the McElmo. Newberry expressed no positive opinion as to the age of the bone-bearing horizon, but called it "Jurassic(?)" in his "General section of the Valley of the Colorado" (**28**, p. 99).

The saurian bones found by Newberry were described by Cope (**2**, p. 31) as the type of *Dystrophæus viæmalæ*, and were said in positive, but quite unwarrantable, terms to have come from the Triassic, with no suggestion of the provisional assignment to the Jurassic by

Newberry. Cope states that Newberry excavated the bones of Dystrophæus "from the red and green rocks usually referred to the Trias, hence from the same formation which yielded the *Typothorax* already described." The *Typothorax* in question was found in New Mexico with belodont crocodile and other forms almost demonstrating that its horizon is the fossiliferous zone of the Dolores Triassic formation, the place of which in the Grand River section is nearly, or quite, 1,000 feet below the McElmo beds, as will be shown in a later section. Cope adds emphasis to his error as follows: "More than usual interest attaches to this fossil. It is the first one found in the Triassic beds of the Rocky Mountain region. . . . ." "The rock is described by Professor Newberry as the same as that which I have identified in New Mexico as the Trias and is of the usual red color" (**2**, p. 36*a*). In harmony with the occurrence of *Distrophæus viænalæ* in the McElmo beds it has recently been pointed out by F. von Huene that its affinities are Jurassic rather than Triassic (**20**).

That the McElmo beds contain the vertebrate fauna of the "*Atlanta-saurus* beds" of Marsh has been demonstrated by Riggs who discovered many dinosaurian remains in that formation near the junction of the Grand and Gunnison Rivers at the northeastern base of the Uncompahgre Plateau (**34**, p. 651). While this vertebrate fauna has not as yet been described, it is referred to by Riggs as clearly the same which characterizes the Jurassic beds of Wyoming and the eastern base of the Front Range in Colorado. It is said that "Representatives of a single genus (*Morosaurus*) have been observed to range through the entire series," meaning a section some 500 or 600 feet in thickness below the Dakota.

It is to be regretted that Riggs did not make the importance of his discovery in the correlation of the Colorado Jurassic more evident to the general reader by a reference to the literature concerning occurrences of supposed Jurassic in western Colorado. There is no mention of the beds for which Eldridge proposed the term Gunnison in the Anthracite-Crested Butte folio (1894), nor to my division of the Gunnison into McElmo and La Plata formations in the Telluride folio (1899). Riggs applies the term "Como beds" to the "Dinosaur beds" of Wyoming and Colorado, although Morrison (Eldridge, 1894)

and Gunnison both antedate Como by several years, if I am correct in thinking that the first definite proposition to use Como as a formation name was made by Scott (**35**, p. 477) in 1897.[1]

Beneath the vertebrate-bearing fresh water Jura are 100 to 120 feet of "bluish and grayish gypsum-bearing clays in which thin layers of fine-grained sandstone and nodular ledges of limestone are interspersed." These Riggs refers to the "marine Jura," although they are destitute of fossils. This assignment must be considered questionable in view of the fact that no marine Jurassic beds are known in Colorado except in the northwestern part where they apparently are to be correlated with occurrences in Utah and Wyoming. The few hundred feet of reddish sandstones below the "marine Jura" are referred by Riggs to the Trias, in accordance with Peale's view. This assignment will be discussed in the next section. The underlying pre-Cambrian granite is spoken of (perhaps inadvertently) as "intrusive" in the sandstones.

LA PLATA FORMATION

The term La Plata formation has been applied in the San Juan folios and other publications to the lower part of what Eldridge described as the Gunnison formation (**13**).

The La Plata consists of two massive sandstone members with an intermediate member of more thinly-bedded sandstones and a variable amount of bluish freshwater limestone. The sandstones are commonly not indurated as in the Elk Mountains; instead they are rather friable and crumbling, although of homogeneous texture. Cross-bedding is a marked feature, and not infrequently a massive ledge as much as 100 feet in thickness has no prominent division planes. Of the two sandstone members the lower is commonly thicker and much more massive than the upper. The latter is in fact occasionally thin-bedded and shaly and may be inconspicuous.

The calcareous member is very variable in character. On the San Miguel River, in the Telluride quadrangle, it is in some places

[1] The reference by Knight to the Como beds as ***marine*** (*American Journal of Science*, 3d Series, Vol. V, 1898, p. 380) is clearly a mistake as he later names the ***marine*** Jura of Wyoming the Shirley beds, reserving the term Como beds for the *freshwater* strata above the Shirley (*Bulletin of the Geological Society of America*, Vol. XI, 1900, p. 377).

a pure massive blue-gray limestone in several beds and with almost no shale. Usually dark calcareous and bituminous shales and thin-bedded sandstones, with more or less of massive limestone, occur between the two main sandstones and sometimes reach a thickness of nearly 100 feet.

The total thickness of the La Plata formation varies, in the area we have examined, from about 100 feet in the Ouray and Telluride quadrangles to 500 or more in the La Plata mountains, and it is known that to the west all members increase still further in thickness.

The sandstones are almost wholly quartzose, and their normal color adjacent to the San Juan Mountains is white or gray; but yellow, orange, and red tints have been observed in that region. The cement is often calcite.

In the Red Beds paper (**8**) were given the observations of Spencer, who traced the La Plata sandstones to Paradox and Sindbad valleys, west of the Dolores, and of Gane, who followed them down the San Juan Valley to the Colorado Canyon. Both noted the prevalence of orange or pink color in the lower country.

On the strength of these observations and a study of literature it was concluded that "the La Plata Formation is seemingly equivalent to the White Cliff sandstone. Its local assumption of red color has led to confusion with the Vermilion Cliff in certain districts and a reference to the Trias." This correlation is considered to be amply substantiated by the recent observations. As this matter is of much importance to an understanding of Plateau geology the grounds for this correlation will be given in some detail.

The first point to be considered will be the relation of the La Plata sandstones of the San Juan slopes to the "Triassic" of Peale in the Uncompahgre Plateau and lower Dolores Valley. The continuity of the La Plata exposures from the Telluride area northwesterly through the San Miguel Canyon and Plateau to the slopes of the higher Uncompahgre Plateau leaves no room for doubt that the upper part of Peale's "Triassic" consists of the La Plata. Moreover, a careful examination of Peale's descriptions of the "Triassic" sandstone shows that characterization to be fully in harmony with this idea. He repeatedly emphasizes a distinction between the upper, light-colored and the lower dark-red sandstones. To illustrate this

the following quotations among many that might be made will suffice. Speaking of the "Triassic" at the head of the Little Dolores, the north end of the Uncompahgre Plateau, he says: "The upper beds of the formation, as usual, are lighter colored than those below. Near the heads of the creeks they are orange-yellow, becoming pink as we go north. Immediately beneath them we have blood-red sandstones which rest on gneissic rocks (**29**, p. 48). In the Unaweep Canyon he says that: "The white or orange-colored, cross-bedded, massive sandstone forms the top of the series" (**29**, p. 81). And again the expression, "the cross-bedded, white sandstone of the Upper Trias," is used (**29**, p. 82).

In characterizing the sandstones on the west side of the Plateau north of San Miguel River he remarks: "The upper portion of the Triassic beds in this region are light colored; in fact in many places they are almost white, and it is only by noticing their structure, which remains the same whatever the color, and watching the change in color, with their position in relation to the remaining strata, that we can identify them. Another point to be noted here is that they are directly superimposed on the Archean rocks" (**29**, p. 55). This last sentence refers to the unconformity between the La Plata and the red Triassic sandstone, which will be discussed farther on in this paper.

From the Dolores Valley the La Plata sandstones are continuously exposed, through Paradox and Sindbad valleys, around the northern and western slopes of the La Sal Mountains to the broad plateaus bordering Grand River Canyon below Moab. Peale examined this area from the summits of the La Sal Mountains (**29**, p. 60), and Holmes viewed them from the similar commanding peaks of the Abajo group. The simple stratigraphy of the area, as far as the section from the Dakota to the Trias is concerned, was an open book to these experienced field observers, and they agreed in extending the units of the areas they had examined in detail through the low country which was hurriedly traversed by Peale.

As the La Plata formation can be traced to the walls of Grand River Canyon below Moab, there is little room to doubt its further extension to the junction with Green River, some 30 miles, and thence down the Colorado to the mouth of the San Juan Valley, 70 miles further, to the point where it was traced by Gane, as mentioned.

As far as I am aware no geologist has described the wonderland lying between Grand River and the Cretaceous divide between the La Sal and Abajo Mountains since the vivid pen pictures of Newberry in his report of the Macomb expedition (28). Nor can one easily equal the clearness with which the broader features of this fascinating region are portrayed. To one familiar with the formations Newberry's descriptions are for the most part easily interpreted.

Descending from the Great Sage Plain, with its Dakota floor, one passes first some 500–600 feet over the steep slope where the soft sandstones and red or green shales of the McElmo occur, but are seldom well exposed. Below them is the upper sandstone of the La Plata, about 300 feet in thickness, which forms low mesas or ridges between the branches of Dry Valley, the main floor of which, over wide stretches, is near the upper surface of the lower La Plata sandstone. The upper member is a fine and even-grained massive sandstone, strongly cross-bedded, of yellowish or pinkish color, and lends itself to a very characteristic sculpturing. We fell at once into the habit of calling this member of the La Plata in Dry Valley the *alcove sandstone*, from the numerous recesses exhibited in nearly all its cliff exposures. Newberry illustrates this feature of a hill called by him "Casa Colorado," and in the files of the Geological Survey is a photograph by W. H. Jackson, clearly of the same subject, reproduced here as Fig. 1.

Certain remnants of the alcove sandstone now standing as isolated hills are very striking. One of these, known as Looking-glass Rock, is situated southwest of the La Sal Mountains near and east of the road from Monticello to Moab. It is represented in Fig. 2. Another remnant of erosion is shown in Fig. 3. Near the base of this knoll a band of marked red color transgresses the stratification very markedly, serving to show the secondary origin of the red color in this case.

The massive character of the upper La Plata sandstone is further illustrated by Fig. 4, representing the cliffs of the upper La Plata in the canyon of Grand River a few miles above the Moab ferry. The incipient alcoves at this point seem largely due to jointing.

The middle calcareous member of the La Plata is apparently represented in Dry Valley by less than 100 feet of thinly-bedded strata, sandstones for the most part, with shaly and impure cal-

careous layers between. The latter are often nodular in development and a pure blue limestone like that of the San Juan region was not seen. In color these beds are apt to be darker red than the massive sandstones above and below, but some layers are gray or yellowish. These beds are seen in Fig. 3 at the base of the sandstone mass.

Below the floor of Dry Valley is the lower La Plata sandstone in a thickness of about 250 feet. It is well shown in Cañon Colorado,[1] (Newberry) and its branches, through which the drainage of Dry

FIG. 1.—"Casa Colorado" (Newberry). In Dry Valley, Utah, near Cañon Pintado. Made of friable sandstones of the upper La Plata formation, Jurassic. Exhibits the alcoves which are very common in this sandstone in the Grand River district. Photograph by W. H. Jackson.

Valley and the southwest slope of the La Sal Mountains enters Grand River.

The lower La Plata sandstone of the Grand River region is more indurated than the upper and is specially distinguished by its cross-bedding. It is light pink or gray, of even fine grain, but is not so notably uniform as the upper. Fig. 5 illustrates a characteristic bank of this sandstone on a small tributary of Cañon Colorado.

[1] The Hayden *Atlas* maps apply this term to the broad shallow part of Dry Valley but on the sketch map of Peale's report for 1875 the name is applied in accordance with Newberry's usage.

Newberry's descriptions and sketches show how strong these characters are in the greatly dissected country adjacent to Grand River.

The base of the La Plata sandstone is probably to be taken as at the horizon where the light-colored, cross-bedded, massive strata give way to dark red sandstones of the Trias. The unconformity or stratigraphic break below the La Plata, discussed in the next section, is not always in evidence in the Plateau country and indeed there is in many places as near an approach to perfect conformity as is commonly found within a given formation between sandstones of different textures.

On the northern side of Cañon Colorado, near its head, the La Plata rests on thin-bedded reddish sandstones of fine grain near the top of which are calcareous layers. Some of the beds contain small chert fragments. In Fig. 6 is shown the nearly white, cavernous, cross-bedded strata, at the base of the La Plata, immediately beneath which are the strongly calcareous sandstones of dark-red color which on weathering yield large nodular masses, such as those in foreground. This is believed to be the line between the Jurassic and Triassic beds at this point.

The continuity of the La Plata sandstone from the San Juan Mountain flanks down the Dolores and San Miguel valleys, around the La Sal Mountains to Grand River Valley, may be said to be perfectly plain and incontestible. In this distance the most notable change in the formation is its increased thickness. The massive texture and even grain of many strata, cross-bedding, variation in color, and other marked features are but emphasized by the greater, volume. The intermediate strata are most variable in character, yet everywhere the two great massive sandstone members are separated by beds distinguishable through their thin bedding, darker color, and richness in calcareous cement or development of limestone.

From the district covered by our reconnaissance the ledges of gray, pink, or orange La Plata sandstone can be seen stretching to the west and south into the belt traversed by Green and Colorado Rivers, where Powell has described the White Cliff sandstone. This great unit in the Plateau country section was never described accurately nor in detail for any given locality, but there seems to be no ground for questioning the assertion of Powell that this formation is continu-

ous with persistent characters from northeastern Utah to the great esplanade bordered by the White Cliffs in southern Utah facing the Grand Canyon. The characters of the White Cliff repeatedly emphasized are its massiveness, "oblique lamination" or "false stratification," and its white, golden, orange, or light-red colors, which are so brilliant in the desert air.

The upper boundary of the White Cliff is the basal marine limestone of the Flaming Gorge Group, of Powell (**33**). The lower

FIG. 2.—Looking-glass Rock. Near southwest base of La Sal Mountains, Utah, to east of road from Monticello to Moab. Formed of alcove-making upper sandstone of La Plata formation. At rear of recess is an opening through to other side of rock. The scale is indicated by figures of two men outlined against sky through opening.

boundary is less clearly defined in the statements of Powell and others, but, with recognition of the stratigraphic break soon to be mentioned and the marked color line apparently everywhere present at the summit of the Triassic sandstones, it may be hoped that no great difficulties in drawing the base of the White Cliff will be experienced when the attempt is seriously made.

UNCONFORMITY BELOW THE LA PLATA SANDSTONE

The far-reaching unconformity below the fresh-water Jurassic beds of central Colorado, by which they overlap all older Mesozoic

and Paleozoic beds and in many places rest on the pre-Cambrian granites and schists, is well illustrated by the Hayden maps. This overlap is particularly well exhibited in the southern Elk Mountains and some of its details are shown in the Anthracite-Crested Butte folio (13).

The fact that no Paleozoic formations are present in the Uncompahgre Plateau was recognized by Peale and expressed on the Hayden map. If, however, the greater part of Peale's "Triassic" in that area be now referred to the La Plata Jurassic, as has been done in the preceding discussion, the question arises as to whether evidence of erosional unconformity between the La Plata and the underlying Dolores Triassic exists in that area or not. Our observations on this point were quite limited but tend to show that such a break does occur. It is certain that in the vicinity of the Unaweep Canyon the dark-red Triassic strata are much thinner than in the Dolores Valley to the west and this decreased thickness appears to be principally due to erosion of the massive red sandstone forming the upper part of the Triassic.

On the north side of West Creek, which is the western stream flowing out of Unaweep Canyon, Messrs. Emmons and Kay found the La Plata to rest on granite near the shore line of the Permian (?) beds which will be discussed in another part of this article. At the head of West Side Creek a few miles south of the Unaweep the pink La Plata sandstone rests on thin-bedded sandstones and shales belonging to the lower part of the Dolores formation, as shown by the pressence of the fossiliferous "Saurian conglomerate." Near the head of Atkinson Creek on the western side of Uncompahgre Plateau, the La Plata seems to rest on gneiss, according to the statement of Peale cited on p. 643.

These facts and the evident variation in thickness of the massive Dolores sandstone, which we noticed at many places, seem to speak for a relation of the La Plata and Dolores very similar to that existing on the western and southwestern slopes of the San Juan Mountains. But much more careful observation is needed in the Uncompahgre Plateau to determine to what extent the absence or variable thickness of the Triassic beds is due to pre-La Plata erosion. Personally, I believe that the Triassic beds were originally deposited over the Uncom-

pahgre Plateau and indeed all of western Colorado, and that they were in some places entirely removed by the erosion under discussion, but this view is not yet supported by enough evidence to warrant a positive assertion.

FIG. 3.—A remnant of upper La Plata sandstone in Dry Valley, Utah. The lower massive sandstone is zone generally characterized by alcoves. The weathering forms shown in cap of hill are very characteristic.

TRIASSIC FORMATIONS

Immediately below the White Cliff sandstone of the Plateau country comes another wonderful formation named by Powell the Vermilion Cliff sandstone (31) which has been recognized by Gilbert, Dutton, and other explorers of the region. Its continuity from the Uinta Mountains to the Vermilion Cliff, which forms the next great step below the White Cliff, facing the Grand Canyon of the

Colorado, is unquestioned, and all observers have referred it to the Trias. It is characteristically developed on Grand River.

Below the Vermilion Cliff sandstone of the classic Plateau section comes a series of beds originally called by Powell (**33**) the "Shinarump group," and for it the early observers claimed the same widespread distribution as for the overlying formations. Referred as a whole to the Trias by Powell, it was long ago shown by Walcott (**37**) that the lower portion of the Shinarump group of the type locality was Permian (?). Our observations on Grand River show that the strata below the Vermilion Cliff sandstone, corresponding in position to the Shinarump, are of very different character from those of the typical section of that group.

In the Red Beds paper (**8**), I suggested that the Dolores formation of Colorado includes diminished equivalents of the Shinarump group and Vermilion Cliff sandstone of the plateau province. With qualifications as to the Shinarump this view has been substantiated. The importance of the relations discovered on Grand River requires a preliminary review of the essential features of the Dolores formation as an aid to a comprehension of the new data.

The Dolores formation of the San Juan region.—The name Dolores Formation has been proposed for the Triassic portion of the Red Beds of southwestern Colorado. It is now known to embrace but a few hundred feet of strata, with stratigraphic breaks, represented in some localities by definite unconformities, both above and below. In the San Juan country the Dolores consists of an upper, dark red, fine-grained sandstone, of variable thickness, in consequence of the pre-La Plata erosion just discussed, and of a lower sparingly fossiliferous succession of sandstones, shales, and peculiar conglomerates.

The thoroughly diagnostic element of the Dolores formation is a certain kind of fine-grained reddish or grayish conglomerate, occurring constantly at its base and repeated in variable development at several horizons in the lower 200 or 300 feet of sandstones and shales. The pebbles of these peculiar conglomerates are commonly very small in some places, resembling pisolitic grains, and appear to be derived from the breaking-up of limestone beds in process of formation; at least, they are not from the bluish fossiliferous limestones of the

Carboniferous section and they are rarely associated with pebbles of other rocks.

In this limestone conglomerate occur almost everywhere small fragments of bone and occasional teeth, vertebrae or other small bones, which have been identified by Lucas as belonging to belodont crocodiles, or to dinosaurs of megalosauroid types. Unios, gasteropods, and plant remains are sparingly associated with the vertebrates.

In the Red Beds paper (**8**) the wide distribution of this fossil-bearing conglomerate was pointed out and the even greater extent

FIG. 4.—The La Plata sandstone. In Canyon of Grand River a few miles above ferry at Moab, Utah. The massive beddings are specially marked in this vicinity. Through irregular jointing rude alcoves have been initiated, suggesting one of the processes involved in their formation.

of the fauna it carries. It is necessary here merely to repeat that the peculiar conglomerate with its upper Triassic fauna, marks a horizon of great importance in the stratigraphic column of the Plateau country and the adjacent mountain slopes. The importance of this horizon is further emphasized by the fact that at Ouray, on the north flank of the San Juan Mountains, the "saurian conglomerate" is found to rest unconformably on the Permian (?) red beds and on the fossiliferous Pennsylvanian section below them, testifying to an important stratigraphic break.

Statement of new observations.—In the Grand River Valley a deep red sandstone, which is clearly the Vermilion Cliff, occurs everywhere in its appropriate place beneath the White Cliff or La Plata sandstone. It was first noted by us in the canyon which appears to be the Cañon Colorado of Newberry, where it presents the aspect shown in Fig. 7—the point of view being within a few yards of that of Fig. 6. The massive wall of this canyon is of a fine-grained, dull, deep-red sandstone, about 200 feet in thickness. The thinner-bedded strata, seen in the view above the massive portions, are of a similiar dark-red color. The basal beds of the La Plata are represented in the knoll on the sky line at the left hand.

The dark-red sandstone seen in the gorge of Fig. 7 has ample opportunity to display its cliff-making capacity in the Grand River Valley, as illustrated in the views of Figs. 8 and 9. The massive sandstone is there seldom more than 200 (?) feet thick, but a vertical jointing, common in the formation, leads to vertical cliffs in many places. As noted by Powell and Dutton the more massive part is almost always overlain by about 100 feet of beds of nearly identical character except for the thin-bedding and local tendency to shaly development. Similar strata underlie the cliff-making portion of the formation, as seen in Figs. 8 and 9.

Not more than 100 feet below the cliff sandstone there occurs on Grand River a thin conglomerate, chiefly of limestone, carrying sparingly, but constantly, fragments of bones and teeth of belodont crocodilean or dinosaurian animals. Both in details of character of the conglomerate and of the fossils it carries, as well as in stratigraphic position, this stratum is clearly identical with that at the base of the Dolores formation in the San Juan region. It is present in corresponding position wherever we examined sections carefully, near Moab, in the Grand River Canyon some miles above Moab, on the north slope of the La Sal Mountains, in Paradox Valley, and on West Creek.

The assertion that the fauna contained in the Triassic beds of Grand River is identical with that occurring in the Dolores formation of Colorado is frankly not supported positively by a large amount of evidence in the form of identifiable fossils. On the east side of Grand River near the road to the ferry, Mr. Kay obtained a vertebra con-

cerning which Mr. J. M. Gidley of the U. S. National Museum reports that "though somewhat crushed and weathered, it is recognizable as belonging, probably, to a Triassic form of carnivorous Dinosaur, although it may possibly be referable to a genus of Belodont. It is certainly reptilian and of a more advanced type than any I know from the Permian."

On West Side Creek, a branch of West Creek, where the Trias is represented only by its lower beds, resting on the Archean (see p. 648),

FIG. 5.—This cross-bedded lower La Plata sandstone. View in a ravine tributary to Cañon Colorado. This cross-bedding stands out prominently in most cliff exposures.

a fragment of bone was found in the limestone conglomerate, which Mr. Gidley considers with reasonable certainty to be "a portion of a fibula (lacking the distal end) of a carnivorous Dinosaur probably of Triassic age."

Ill-preserved Unio shells were found in association with the vertebra mentioned. Much better material was obtained in 1901 by Mr. L. M. Prindle, now of the U. S. Geological Survey, in certain of the reddish sandstones between the Vermilion Cliff and limestone con-

glomerate, and through his kindness I am able to give the report made upon these fossils by Mr. T. W. Stanton, as follows:

The collection of invertebrates collected by Mr. L. M. Prindle contains many good casts and imprints of Unio, apparently belonging to three or more species. These are comparable and possibly identical with *Unio cristonensis* Meek, *U. dockumensis* Simpson, and *U. dumblei* Simpson, all of which come from supposed Triassic beds. *Unio cristonensis* was described with two other species from fragmentary specimens obtained by Cope on Callinas Creek, New Mexico. The Moab specimens are much larger than the types but they agree in outline and general proportions. The other two species above mentioned were obtained by the Texas Geological Survey in the Dockum beds of northwest Texas. These beds have yielded four species of Unio, which, with the three species from about the same horizon in New Mexico, are the oldest known representatives of the genus. The species in the Moab collection seem to belong to the same Unio fauna.

That in this vicinity a stratigraphic break of much importance occurs just below the "saurian conglomerate," as it has been called in the San Juan region, is evident on Grand River and at other places. On the west side of Grand River opposite Moab the bone-bearing conglomerate is separated from fossiliferous Pennsylvanian beds by only about 50 feet of shaly sandstone, and it is possible that these beds also belong to the Pennsylvanian series. Details of the section at this point are given on p. 669.

Near Moab, on the northeast side of Spanish Valley, a poorly exposed section reveals about 250 feet of strata, mainly reddish sandy shales, between the "saurian conglomerate" and the uppermost Pennsylvania limestone. On Grand River about 1 mile above the Moab ferry the "saurian conglomerate" reappears above the level of the river, and, as it rises gradually to the northeast for several miles, a larger and larger section of the pre-Dolores strata is exposed, but nowhere so far as our observations go, do the Pennsylvanian beds appear, all the sub-Dolores section belonging to the upper (Permian ?) series of the Carboniferous. This is itself evidence of a great break immediately below the "saurian conglomerate." That the break represents uplift and erosion producing angular unconformity is well illustrated on both sides of Grand River about 10 or 12 miles northeast of the ferry and just below the mouth of Castle Creek, a stream heading on the west side of the La Sal Mountains. Fig. 8

illustrates this unconformity, which may be traced for about half a mile, and it was estimated that at least 600 or 800 feet of beds are visibly truncated by the conglomerate in one continuous exposure. The occurrence of an extensive section of gypsiferous sandstones and shales beneath the Dolores conglomerate in Fisher Valley on the northwest side of the La Sal Mountain adds so much to the beds trangressed; and a still higher series of sandstones and conglomerates is known, so that, altogether, it is estimated that not less than 1,500

FIG. 6.—The lowest strata of the La Plata sandstone, north side of Cañon Colorado near its head. Shows the characteristic cross-bedding and cavernous weathering. Nodular masses on level floor of foreground belong to upper beds of Vermilion Cliff (Dolores) sandstone (p. 646).

and possibly 2,000 feet of Permian (?) or upper unfossiliferous Pennsylvanian beds have been eroded in the locality of the section first mentioned, opposite Moab.

On West Creek, the western stream from Unaweep Canyon, the "saurian conglomerate" is seen overlapping from the heavy conglomerates of the Permian (?) to the granite-gneiss-schist complex of Uncompahgre Plateau. This is the overlap represented on the Hayden Map of western Colorado, and interpreted by Peale as a part of the overlap of all formations from the upper Carboniferous to the

Dakota about an island of ancient rocks which he believed to have never been completely submerged until the Dakota epoch (**29**). This view is manifestly not wholly correct, in that it does not recognize the extent of the denudation of the intervals preceding and following the Dolores epoch. Only the latter of these was known to Peale. As for the uppermost Paleozoic beds of West Creek there is evidence (presented on p. 662) that they do there abut against the granite of a continental mass, as noted by Peale. The point of interest here is that the Dolores conglomerate has no such boundary and was probably deposited on the granites, gneisses, etc., over the whole area of the Uncompahgre Plateau, its absence in any given locality being satisfactorily explained by the pre-La Plata erosion.

From the facts presented, it would seem established that the Dolores formation is represented in the Grand River Valley by the Vermilion Cliff sandstone, together with about 100 feet of thin-bedded sandstones, shales, and limestone conglomerate below it.

Relation of the Dolores conglomerate to the Shinarump conglomerate.—The discovery of the "saurian conglomerate" and the unconformity below it makes it necessary to trace that horizon with care through the Plateau province. There seems to be no suggestion of such a conglomerate in the statements of any writer on the geology of the region, except Newberry. In his "General Section of the Valley of the Colorado" (**28**, p. 99) there is a member, 92 feet in thickness, described as, "Greenish gray micaceous conglomerate and gray sandstone, separated by red and purple shales." This occurs below 350 feet of red sandstone which I correlate with the Vermilion Cliff sandstone, and there is evidently a general correspondence to the 104 feet of strata below the Vermilion Cliff west of Moab. As Newberry measured this member of his section only a few miles below Moab it seems almost necessary to assume that the 92 feet of strata here referred to belong to the lower part of the Dolores, and include the fossiliferous conglomerate. Between this conglomerate and fossiliferous Pennsylvanian limestone Newberry found 514 feet of sandstone described as liver-colored, brick red, or white, with shale partings. Clearly the gypsiferous series of Fisher Creek, the overlying conglomerates and sandstones, and a considerable part of the underlying Permian (?) beds are absent on the line of Newberry's

section, implying a stratigraphic break comparable to that we found, and the probable horizon of the break is below the conglomerate.

The question as to the correlation of the Dolores formation with some portion of the Plateau section generally assigned to the

FIG. 7.—Near head of Cañon Colorado, Utah. Shows massive Vermilion Cliff (Dolores) Triassic sandstone, thinner sandstones above, and, in knoll on left hand, the lowest sandstones of the La Plata Jurassic.

Trias becomes mainly a study of what has been called the "Shinarump Group" by Powell and particularly of the relatively thin bed called the "Shinarump conglomerate." I have made such a study and

embodied the result in a paper which will appear in this journal during the current year. A brief summary of certain facts and conclusions will suffice in this place.

The Shinarump conglomerate, named by Powell (**31**), is in the midst of a series of strata well shown to the north of the Grand Canyon called the Shinarump Group by Powell (**33**), who believed the whole to be Triassic. Gilbert (**14**), Walcott (**37** and **38**), and Dutton (**9**) have observed unconformity by erosion below the conglomerate, while Walcott obtained Permian fossils in the lower part of the group in the typical Kanab section, and since that discovery geologists generally have adopted Walcott's view that the Shinarump conglomerate should be taken as the base of the Trias of the Plateau Province.

The correspondence in stratigraphic position between the Shinarump and the lower conglomerate of the Dolores formation naturally suggests their identity and I am strongly inclined to believe that they will ultimately be found to occur at the same horizon. There are, however, some discrepancies and apparent differences between the observed sections that must be explained before this opinion can be accepted.

It has been asserted by Powell and Dutton in almost unqualified terms that the Shinarump group extends from the Grand Canyon district to the Uinta Mountains, and Dutton has named the junction of the Grand and Green rivers as a locality where the whole group is present in typical development (**9**, p. 144) and where the conglomerate bed exhibits the same characters as in the Shinarump Cliff of southern Utah (**10**, p. 208). Both assertions seem to have been based on insufficient knowledge of the section below the Vermilion Cliff sandstone, for no descriptive data appear in the reports of these geologists to substantiate the claim. As far as I can ascertain, no geologist except Powell has examined the section near the confluence of the Grand and Green Rivers and he gives in his reports only general statements concerning the strata between the Vermilion Cliff sandstone and the Carboniferous beds referred to the Aubrey.

In the vicinity of the Henry Mountains Gilbert reports (**14**) a stratum correlated by him with the Shinarump conglomerate at 350 feet below the Vermilion Cliff sandstone, and some miles southeast of the Henry Mountains at Clay Hill divide, H. S. Gane found (**7**)

a Triassic crocodile, *Heterodontosuchus ganei* Lucas (**24**) with fossil wood in limestone conglomerate near the base of the Dolores formation. Gane was familiar with this formation and traced it to Clay Hill from southwestern Colorado. The beds are apparently continuous westward to Glen Canyon of the Colorado about 20 miles. This observation of Gane is most important as bringing what I think can be unhesitatingly considered to be the fossiliferous zone of the Dolores formation into the heart of the Plateau country. Actual

FIG. 8.—View in canyon of Grand River about 12 miles above ferry at Moab, Utah. Looking west across river; to show angular unconformity at base of Dolores Triassic beds. Cliffs of columnar rock are formed of Vermilion Cliff sandstone. Beds beneath unconformity are considered to belong to Permian (?).

demonstration of the relation of the Clay Hill fossil-bearing conglomerate to the Shinarump conglomerate is yet to be furnished.

One can scarcely question that Powell, Dutton, Walcott, and others have applied the name Shinarump conglomerate to a single bed or formation commonly less than 100 feet thick, as far as the country west of the Colorado is concerned, from the mouth of Paria Creek to the vicinity of St. George, Utah. No fossils have been found

in it and it has not been described in detail as to the character, size, and abundance of the pebbles. But from the mouth of Paria River southeast, below the Echo Cliffs, which are mainly formed of the Vermilion Cliff sandstone, the Shinarump conglomerate has unfortunately not been absolutely traced, so that its relation to the vertebrate-bearing beds found by Ward in the Little Colorado Valley is uncertain. The vertebrate fauna obtained by Ward and Brown (**39**, **40**) from several localities near the Little Colorado from the midst of the strata, rich in fossil wood, is clearly the same as, or similar to, that so widely known in the Dolores formation, the most common form being the crocodile of which the type was found by Gane in the Dolores at Clay Hill. Ward does not identify the Shinarump conglomerate as a single marked bed, but applied the term to 800 feet of strata entirely below the vertebrate-bearing horizon (**40**). Dutton, on the other hand, has thought to recognize the Shinarump conglomerate in typical development as far east as the Zuni Plateau in New Mexico (**11**).

At the present time, it seems to me not improbable that the horizon of the original Shinarump conglomerate of the Shinarump Cliffs is near, if not equivalent to, the vertebrate-bearing strata of the Little Colorado Valley, being there perhaps less conspicuously conglomeratic than in the type locality. The "conglomerate" is usually described by Dutton and others as really a coarse sandstone with pebbles irregularly scattered through it. Dutton ascribes a fluviatile origin to it, and such is also clearly the mode of formation of the Dolores conglomerates, which vary greatly in character in different places. It is surely not unlikely that beds of this character, but of different horizon, have been mistaken for the same by reconnaissance observers at widely separated points. This might be suspected from the character of the so-called conglomerate alone, and is rendered quite plausible by Ward, who found sandstones containing some pebbles variably developed in different sections through some 800 feet of strata (**40**).

The occurrence of a vertebrate fauna of upper Triassic age over a wide expanse of country, in Arizona, Utah, Wyoming, Colorado, New Mexico, and probably also in Texas, seems the most definite fact from which to start in studying the problem of the western Trias.

CARBONIFEROUS FORMATIONS

Sedimentary formations of the Carboniferous System are but sparingly exposed in the eastern part of the Plateau country, erosion having penetrated to them in only a few places. They were found by

FIG. 9.—View in Grand River Canyon at mouth of Castle Creek, Utah. Shows characteristic scarp of Vermilion Cliff sandstone. Probably about 100 feet of thin-bedded strata below belong to Triassic and remainder to Permian (?), the unconformity between them not being exhibited.

Peale in the valleys of Grand and Dolores Rivers and in Paradox and Sindbad Valleys. While the Triassic and other Mesozoic rocks of the Plateau district can be traced continuously to the mountains of Colorado, the correlation of the Paleozoic formations depends entirely

upon stratigraphic position in different areas and on inherent characters.

In the area under discussion, Peale distinguished an unfossiliferous series of red beds lying below the Trias, and a fossiliferous series of still lower horizon. The former he mapped as "Upper Carboniferous," though often referring to it, in his reports, as possibly Permian, and the latter was referred to the "Middle Carboniferous." During our reconnaissance various observations were made touching the character and relations of both these series.

THE PERMIAN (?) RED BEDS

On Sheet XIV of the Hayden *Atlas of Colorado*, Peale represents "Upper Carboniferous" beds abutting against granite on West Creek near Dolores River, and thence extending westerly to the canyon of Grand River in Utah. The same formation is shown in Paradox and Sindbad Valleys. While the general distribution of the pre-Triassic red beds is no doubt fairly represented on the Hayden map, Peale was unable to make sufficiently detailed study of the formation to correlate the various partial sections examined. Our observations were also far too incomplete to permit of a satisfactory description of the whole section. This is the more difficult because of a gradual change in the character of the formation as distance from its eastern border increases.

It was observed by Peale that the "Upper Carboniferous" beds near the granite on West Creek were conglomerates rich in granite, "proving that during their deposition there was adjacent land of which the rocks were granite" (**29**, p. 56). He also represents a shore-line near this locality, in profile sections across the Uncompahgre Plateau (**29**, Plate IV). Owing to "a steep dip" of the conglomerates away from the granite Peale does not place the shore-line immediately at the contact seen crossing West Creek; but, as no "Middle Carboniferous" strata are present adjoining the granite the boundary does in fact represent correctly the overlap.

That the strata in the vicinity of the granite do dip westward at angles of 15° or more is true, but in a ravine on the south side of West Creek and about ½ mile from it, I observed grits to rest directly on granite with a westerly dip of 12° to 15°, exhibited in strata near

the base. No fault was found, and it seems to me improbable that the boundary is of that nature in the vicinity of West Creek. Where the sediment was seen resting on granite, the lower layers consisted

FIG. 10.—In a ravine on south side of West Creek, Colorado, about 5 miles east of Dolores River. To show character of Permian (?) conglomerates and grits very near granite mass of Uncompahgre Plateau from which they were derived (p. 662).

of coarse, angular gravel, scarcely bedded at all. At a distance of a few feet above the granite bedding planes become more distinct, through alternation of finer and coarser material aided by color differ-

ences, the finer-grained material being reddish. At 25 feet above the granite the characteristic alternation of grit and conglomerate began. But the distribution of pebbles and bowlders is very irregular, the latter are often subangular, and the whole is so little consolidated that the disintegrated beds seem like surface gravels. Fig. 10 shows the appearance of the beds in the ravine in question. It is but a few hundred feet from this point to the contact which was seen.

FIG. 11.—Looking southward across West Creek, Colorado, near mouth. Canyon of Dolores River faintly outlined on right. The upper cliffs of view are caused by massive La Plata sandstone (Jurassic). Next lower cliffs and headlands on right are formed of Dolores or Vermilion Cliff Triassic sandstone. Below latter, section is that discussed on p. 667, and referred to Cutler Permian (?).

Similar coarse conglomerates occur along the road on the north side of West Creek, seeming there like partially consolidated stream gravels, but examination shows them interbedded with finer grits of the series.

At about 3 miles west of the granite line on the south side of West Creek, Mr. Woolsey measured the following section of sub-Triassic strata, the locality being below the central point seen in Fig. 11.

SECTION ON SOUTH SIDE OF WEST CREEK (L. H. WOOLSEY)

		Feet
	Top. Triassic red beds.	
20.	Conglomeratic grit, fine-grained, pinkish	50
19.	Interval, mainly covered by talus, but with pinkish grit revealed here and there	140
18.	Interbedded arkose and shale grading upward into shale	8
17.	Conglomerate, containing pebbles 4–5 inches in diameter, of various granites, in matrix of red arkose sand	2
16.	Covered interval	30
15.	Friable grits not well exposed and probably very similar to No. 14	80
14.	Conglomerate and fine arkose, interbedded, the pebbles generally of coarse granite and gneiss, up to 12 inches in diameter	35
13.	Covered by talus	75
12.	Arkose, red, fine-grained, with occasional pebbles of granite or greenstone, 3 inches diameter	42
11.	Concealed by talus	13
10.	Conglomerate of gneiss and coarse granite; bowlders up to 12 inches diameter; arkose matrix	5
9.	Concealed by débris, but apparently like	20
8.	Conglomerate arkose, alternating fine and coarse; the finer-grained parts are similar to No. 7; the conglomerate carrying bowlders of various granites up to 6 inches diameter	30
7.	Arkose, reddish, mostly fine-grained with pebbles 1 inch or less in diameter; occasional bowlders of different granites to 9 inches; toward top becomes interbedded with thin red shale layers, but lenses of bowlders are also present in this upper part	135
6.	Conglomerate, coarse, the granite and gneiss bowlders reaching 1½ feet in diameter, the largest ones near top, rests unconformably on 5	5
5.	Arkose grit and red shale alternating; 4 feet of fine-grained arkose at base, with thin seams of shale; these become more and more prominent toward top; coarse lenses of conglomerate at several horizons; isolated bowlders occur in certain shale layers	15
4.	Arkose grit, reddish, grading into coarse conglomerate at top, containing some bowlders 1½ feet in diameter	10
3.	Shale, red and green, irregular in thickness, owing to erosion	2
2.	Arkose grit, dark reddish, conglomeratic and seldom cross-bedded, the coarser parts in lenticular bodies; granite pebbles reach 6 inches diameter; a few pebbles of greenstone, the great majority being granite or gneiss	32
1.	Grit-conglomerate, gray, pink, or purplish, in massive cross-bedded banks, with numerous layers of fine grain, and usually darker color	150
	Total	879

The pebbles of the conglomerate strata of this section are principally of granite and the most abundant variety is the very coarse-textured one with large orthoclase crystals occurring in the nearest exposures of the Uncompaghre Plateau. Among the pebbles are some of greenstone schist which indicate that the pre-Cambrian complex furnishing this material is similar to that from which the Cutler conglomerate of the San Juan was derived. Similar greenstones were observed in the conglomerates of Grand River Valley.

Below the measured section there may be several hundred feet of similar strata, for the somewhat deeper cutting of Dolores River does not reveal the base of the succession of grits and conglomerates. The next lower formation is probably a series of gypsiferous shales and sandstones and the nearest locality at which such strata are known to occur is in Sindbad Valley, 12 miles south from West Creek. A fault running near the base of the northeastern scarp prevents a clear determination of the relations but the gypsiferous beds are manifestly older than the strata below the Dolores. These belong no doubt in the series measured on West Creek. Owing to complex folding and faulting to be discussed on another page, the extent and relations of the gypsum-bearing beds cannot be ascertained, but they are apparently some hundreds of feet in thickness.

That the gypsiferous section occurs between two series of sandstones, shales, and conglomerates, is indicated by the observations on Grand River (p. 654). In discussing the unconformity at the base of the Dolores, it was stated that going northeast from Moab, up Grand River, a succession of shales, sandstones, and conglomerates appears between the fossiliferous Pennsylvanian beds and the Dolores. The structure brought out in Fig. 8 shows that the intermediate beds rest on the Pennsylvanian.

At the time we traversed Grand River Valley, we did not know of the existence of the gypsiferous beds in that region, but on the way to the northern stope of the La Sal Mountains in the valley of Fisher Creek a considerable thickness of such strata was found. As in Sindbad Valley, a zone of faulting and folding interferes with an accurate determination of relationship on the line of travel.

No doubt the detailed nature of the section between the Pennsylvanian and Triassic can be fully determined in Grand River Canyon,

and without difficulty. A few miles above the point at which we left Grand River, Boutwell found a section of "light pinkish-purple, shaly sandstones which include coarse cross-bedded sandstones and conglomerates with well-rounded granite and porphyry pebbles" under a massive sandstone which corresponds to the Vermilion Cliff (1). These might belong to the section resting on the Pennsylvanian beds near Moab, but seem much more probably to represent strata above the gypsiferous beds and roughly equivalent to those seen on West Creek.

Comparing the strata known on Grand River between the Dolores base and the Pennsylvanian limestones with the Cutler formation (Permian ?) of the San Juan Mountains it is clear that the gypsiferous part of the series has no similar representative in the mountain district. If such beds ever existed in the San Juan region, they were removed prior to the deposition of the saurian conglomerate, and this does not seem at all unlikely, for gypsiferous beds are known in the Paleozoic red beds of northwestern Colorado, as reported by Peale (**29**).

The grits and conglomerates of West Creek are so near their source that they differ from the Cutler beds in being much coarser and more strongly arkose, but the section seen on Grand River and Fisher Creek certainly resembles in lithologic character the Cutler beds of the Uncompahgre Valley below Ouray, and appears to occupy the same stratigraphic position.

The Cutler formation and the pre-Dolores red-bed strata of Grand River clearly correspond to the lower part of Powell's Shinarump Group, that is, to the "Permo-Carboniferous" of the Wasatch and Uinta Mountains, according to the nomenclature of the Fortieth Parallel Survey, or to the Permian of Dutton, in the Grand Canyon monograph. Fossils indicating a Permian or Permo-Pennsylvanian age were found by the Fortieth Parallel geologists in the Wasatch Mountains and by Walcott in the Kanab Valley of northern Arizona. The apparent absence of fossils in most localities where these beds have been examined is no doubt due to the fact that they are mainly continental deposits, an origin indicated by their texture.

The site of one of the land masses from which these deposits were derived is shown by the relations existing on West Creek. Peale assumed that this plateau belonged to an island extending eastward

through the area now traversed by the Gunnison Canyon, where Mesozoic beds rest on the pre-Cambrian complex. This may be true, but it must be borne in mind that the pre-Dolores and pre-La Plata uplifts with their succeeding denudations may have removed the entire Paleozoic section from much of this tract.

As distance from the mountain source of these clastic materials increases, the beds are naturally finer grained and grade into shales and marls, and correlation of widely separated sections becomes difficult. It is evident that the sub-Dolores and probably Paleozoic red beds need much closer study as to their structural relations to the overlying Triassic, as well as careful record of sections at favorable points, before correlation can be made satisfactory.

PENNSYLVANIAN SERIES

Fossiliferous Carboniferous strata were found by Newberry in 1859 in Grand River Canyon and in the lower part of Cañon Colorado. The section referred by him to the Carboniferous was described as follows in the "General Section of the Valley of the Colorado" (**28**, p, 99).

	FEET
14. Blue limestone, somewhat cherty. Fossils: *Spirifer cameratus*, *Athyris subtilita*, *Productus semi-reticulatus*	110
15. Bluish-white, red, or mottled sandy limestone, with partings of red shale	95
16. Hard, blue cherty limestone. Fossils same as No. 14	36
17. Alternations of blue limestone, red and gray sandstone, to bottom of cañon	1,000

On the map accompanying Newberry's report the point at which he reached Grand River is located only about 6 miles above the junc tion with Green River, whereas according to the La Sal sheet of the U. S. Geological Survey, Cañon Colorado, the name of the side gorge descended by Newberry, joins Grand River Canyon at 9 miles below Moab and 24 miles above the union with Green River. Whether Newberry's locality be near the junction of the Grand and the Green, or but a few miles below Moab, it is natural to assume that a fossiliferous Pennsylvanian Carboniferous section discovered by us on the northwest side of Grand River, opposite Moab, is identical stratigraphically with some part of that found by Newberry. The faunal

evidence, however, makes this conclusion more or less open to question, as will appear from the ensuing discussion.

At about three fourths of a mile northwest of Grand River and on the southwest side of the valley traversed by the stage road from Moab to Thompson station on the Rio Grande Western Railroad, there is an excellent section of the strata for several hundred feet below the Vermilion Cliff sandstone. The beds dip gently to the southwest, and it is believed that no fault crosses the line of the section, although its base is immediately adjacent to the southwestern fault of a zone traversing Spanish Valley. The following section, including some of the Triassic beds, was measured by W. H. Emmons and L. H. Woolsey.

SECTION NEAR GRAND RIVER, OPPOSITE MOAB, UTAH

		FEET
	Top	
32.	Sandstone, massive or shaly, dark red at base and bright red at top	20
31.	Shaly, conglomeratic sandstone, reddish limestone pebbles, the size of a pea or smaller, with few bone fragments	6
	Dolores Triassic	
30.	Sandy shale, red and green	5
29.	Débris slope, of red shale fragments	20
28.	Limestone conglomerate, with a few inches of limestone at top, fossil, wood, and bone fragments; pebbles less than 2 inches diameter	10
27.	Sandstone, gray, massive	20
26.	Limestone conglomerate grading into sandstone	1½
25.	Sandstone, gray, massive becoming shaly near top	23
24.	Calcareous sandstone and fine-grained conglomerate, mainly sandy, with conglomerate near base and top. Pebbles of limestone and sandstone with occasional bone fragments; pebbles vary from size of peas to several inches	9
	Permian (?)	
23.	Red sandy shales, alternating with sandstone	8
22.	Conglomerate, containing pebbles of limestone and sandstone	1
21.	Sandstone and shale alternating, red and green, the shales sandy and friable	35
	Hermosa Pennsylvanian	
20.	Blue limestone, weathering dirty buff; near top a layer contains pipe coral	10
19.	Sandstone, thin bedded, some crumbling, some massive, red or gray	40
18.	Gnarly looking bluish limestone, sandy	3
17.	Sandstone, pink to gray, massive, friable	23

16.	Sandstone and limestone in alternating thin layers, crumbling	25
15.	Limestone, blue, weathering buff; crinoid stems near base, corals above	40
14.	Sandstone, light red, fine-grained, cross-bedded	30
13.	Sandstone, gray, massive, calcareous	5.
12.	Sandstone and shale with a few thin limestone layers; nodular forms of weathering common	60
11.	Limestone, blue, gnarly looking, massive	1½
10.	Sandstone red and green layers alternating	12
9.	Sandstone, red, micaceous, alternating with sandy shales	60
8.	Limestone, sandy near base, gnarly, fossiliferous	6
7.	Shale and sandstone, red	10
6.	Sandstone, red	8
5.	Shales, purplish, sandy micaceous, very thin-bedded	4
4.	Limestone, bluish, in hard dense beds, 1 to 2 feet thick, fossiliferous	6
3.	Sandstones, thin-bedded, alternating with purplish sandy shales; sandstone layers less than 3 feet thick	15
2.	Sandstone, bluish-gray, friable, micaceous, cross-bedded	7
1.	Sandstone, gray, green, or purplish red	15
		539

Above this section comes a cliff of red, pink, and gray sandstones apparently embracing the Vermilion Cliff sandstone and possibly a part of the White Cliff sandstone, not examined in detail. No lower beds are exposed in the valley.

The upper 104½ feet of the section represents the fossiliferous Triassic beds immediately below the Vermilion Cliff sandstone which is here well developed. The next 44 feet of beds is provisionally referred to the Permian, and in that case represents the basal portion of that series. It may possibly belong with the underlying Pennsylvanian Series, or partly to the overlying Triassic, if the conglomerate, No. 22 of the section, be taken as the base of that series.

From the limestones of the Pennsylvanian portion of the section, Nos. 1 to 20, inclusive, we obtained the fossils shown by column IV of the table on p. 672. Probably no other exposure near near Moab reveals so great a thickness of the Pennsylvanian strata as that we examined, but doubtless the upper fossil-bearing limestones may be found in Spanish Valley. It is not known whether they are continuously exposed in the canyon of Grand River from Moab to the mouth of Cañon Colorado. The southwesterly dip of the Spanish

Valley anticline brings the Triassic beds to the river level at a short distance below Moab.

Another collection of fossils was made in 1901 by Mr. L. M. Prindle, on the road about half a mile northwest of the locality we studied, from strata visibly belonging to the section given. By Mr. Prindle's courtesy, I am permitted to indicate the forms identified by Mr. Girty in his collection, in column III of the table.

The only other locality where we observed fossiliferous Pennsylvanian beds is on the southwestern side of Sindbad Valley at the same point where Peale found bluish limestone carrying Producti, Crinoid, and Corals. The specimens collected by him were abandoned during an attack by Indians, so that the definite character of this fauna was not determined. In his report, Peale gives a section (**29**, p.71) in which the fossil-bearing strata are placed beneath shaly sandstones having an estimated thickness of 3,500 feet, and above these are the gypsiferous strata of the valley floor. The fault zone parallel to the axis of the valley is more complex than Peale supposed, and it seems probable that the fossil-bearing strata form a narrow and vertically upturned block thrust up almost to the level of the Vermilion Cliff sandstone, and that no continuous section exists in the valley by which the position of these fossiliferous beds in the whole section can be established. They are bounded by a fault on the northeast, as well as on the southwest. These fossil-bearing beds were also examined by Mr. A. C. Spencer in 1899, and a collection of fossils was made.

From the bluish limestone ledges of Sindbad Valley the fossils indicated in column V of the table, p. 672, were obtained, either by Mr. Spencer or by our party.

In view of the meager statements of Powell and Newberry as to the sections examined by them, and the isolation of the Moab and Sindbad Valley occurrences, the most satisfactory basis for a correlation of these Pennsylvanian sections lies in comparing the fossils collected at the several localities. Through the kind assistance of Mr. G. H. Girty, who has examined all the material except the collection by Newberry, I am able to present in tabular form the lists of all known fossils from the localities named. For comparison the known occurrence of the species of the lists in the Hermosa forma-

tion, or in probable equivalents of that formation in central Colorado, is also indicated.

TABLE OF CARBONIFEROUS FOSSILS FROM UTAH AND COLORADO

	I	II	III	IV	V	VI
Syringopora multattenuata				×		
Syringopora sp.			×			
Lophophyllum profundum				?	×	×
Zaphrentis sp.				×		?
Campophyllum torquium			×	×		×
Axophyllum rude				×		
Eupachycrinus platybasis*	×					
Erisocrinus typus	×					
Ceriocrinus inflexus	×					
Echinocrinus cratis	×					CB
Echinocrinus trudifer ?			×			L
Echinocrinus Dinnini ?			×			
Echinocrinus sp.					×	
Fenestella aff. tenax			×			×
Fenestella sp			×			×
Polypora sp.			×	×	×	?
Goniocladia sp.*	×					
Fistulipora sp.			×	×		?
Rhombopora lepidodendroides			×			×
Lingulidiscina sp.					×	
Derbya crassa ?		×*	×	×		?
Derbya aff. robusta	×					
Meekella striaticostata	×					×
Orthotichia Schuchertensis					×	
Enteletes hemiplicatus					×	
Chonetes granulifer	×				×	
Productus semireticulatus	×	×			?	?
Productus semireticulatus var.	×					
Productus Portlockianus					×	
Productus punctatus	×	×	×	×	×	×
Productus Nebraskensis	×	×†	×	×	×	×
Productus aff. Humboldti*	×					
Productus aff. porrectus*	×					
Productus scabriculus*		×				
Productus cora	×			×		×
Productus nodosus*		×				
Productus multistriatus*	×					
Productus subhorridus*	×					
Marginifera Lasallensis				×		CB ?
Marginifera Wabashensis ?	×			×		?
Marginifera ? sp.	×					
Spirifer cameratus	?	×		×	×	×
Spirifer Rockymontanus	×					×
Squamularia perplexa				×		×
Spiriferina Kentuckyensis	×					×
Composita subtilita	×	×		×	×	×
Hustedia Meormoni				×		CB
Pugnax sp.				×		CB ?
Drelasma bovidens				×		CB
Deltopecten Van-vleeti			×			

* Orthisina umbraculum of Newberry. † P. Rogersi of Newberry.

TABLE OF CARBONIFEROUS FOSSILS FROM UTAH AND COLORADO—*Continued*

	I	II	III	IV	V	VI
Myalina Kansasensis..................			?		×	
Myalina ampla........................		×				
Myalina subquadrata..................	u§					?
Myalina Apachesi*....................	u					
Myalina Wyomingensis ?...............	u					L ?
Edmondia subtruncata.................	×					×
Edmondia Mortonensis ?...............					×	
Allerisma terminale..................	×	×‡	×			×
Choenomya Leavenworthensis..........					×	×
Schizodus Wheeleri...................	×					
Schizodus sp.........................	×					?
Pleurophorus sp......................	×					
Bellerophon majusculus*..............	×					
Bellerophon sp.......................	×	×				?
Bellerophon percarinatus.............					×	?
Patellostium aff. Montfortianum........	u					?
Euconispira excelsa*.................	×	×				
Euconispira sp.......................					×	?
Worthenia tabulata ?.................					×	
Euomphalus catilloides...............	×			×	×	×
Euomphalus sp........................	×					
Naticopsis remex.....................	×					
Naticopsis Altonensis ?..............					×	?
Naticopsis monilifera................				×	×	×

* Orthisina umbraculum of Newberry.
† P. Rogersi of Newberry. ‡ A. Subcuneatum of Newberry.
§ Species designated by White as from the "Upper Aubrey" are marked "u."

I. Confluence of Grand and Green Rivers, Utah; collected by Powell expedition, determined by C. A. White (**32**, pp. 88–92).
II. In or near Canyon of Grand River, below Moab; collected by J. S. Newberry, 1859 (**27**, p. 98).
III. On road about 4 miles northwest of Moab, Utah; collected by L. M. Prindle, 1901.
IV. Cliff about 3½ miles northwest of Moab, Utah; collected by Cross party, 1905.
V. Sindbad Valley, on Colorado-Utah line; collected by A. C. Spencer, 1899, or Cross party, 1905.
VI. Occurrence of species of this table in the Hermosa formation of southwestern Colorado, indicated by species not yet found in the Hermosa formation but known from the Crested Butte quadrangle, Colorado, or the Leadville district, are also indicated, by CB or L respectively.

Concerning the faunal relations indicated by this table, Mr. Girty has kindly given me the following comments for publications:

Powell's collection at the junction of the Grand and Green Rivers shows a fauna probably equivalent to that of the Aubrey formation. Many of the charac-

teristic Aubrey forms are, however, lacking (*Productus occidentalis*, *P. Ivesi*, *Allerisma capax*, etc.). This fauna is more like that of the Weber quartzite formation of Bingham, Utah, which, at the present time, I provisionally correlate with the Aubrey. Newberry's list making the necessary synonymic changes is almost identical with Powell's, as far as it goes. The collection is smaller, and, of course, lacks many forms which might be obtained on further search. Considering the Powell and Newberry collections together, it is notable that they contain a considerable number of species which may be called distinctive western types, as compared with the Pennsylvanian fauna of Colorado and of the Mississippi Valley. These species are marked by an asterisk following the names in the list. In some cases nothing at all closely related to the types indicated is known from the region to the east. In other instances there are more or less similar species known which are not yet regarded as identical with western forms, although they may prove to be so.

The collections from Moab consist entirely of typical Pennsylvanian species, lacking the forms specified as characteristic of the far western areas. The distinctly Pennsylvanian forms found at the junction of the Green and the Grand occur, however, at Moab. The Sindbad Valley fauna is very closely related to that from Moab.

In view of the fact that none of these collections can be considered as exhaustive for the localities, numerical comparisons are more or less untrustworthy; yet the table brings out certain contrasts or resemblances which seem worthy of note. Out of 42 species represented in the Powell and Newberry collections but 9 have been found at Moab, or in Sindbad Valley, while out of 43 species obtained in these latter localities 29 are known from the Pennsylvanian rocks of southwestern or central Colorado.

On the basis of the fossil evidence alone there can be no hesitation in considering the Moab and Sindbad Valley sections as belonging to the Hermosa formation rather than to the Aubrey, as represented in the lower Grand River Valley.

The strong similarity which Mr. Girty has pointed out between known faunas of the Moab district and of Sindbad Valley to that of the Hermosa formation of Colorado, and the contrast with the faunas collected by Newberry and Powell, require some explanation.

As stated on p. 668 the collection made by Newberry was obtained less than 10 miles below Moab, if the Cañon Colorado of recent maps is the same as the canyon of that name through which Newberry descended to Grand River. If he reached Grand River as near to the junction of the Green as he himself supposed, the locality of Newberry's collection was still in all probability not more than 25 miles from Moab. One explanation of the difference between the Moab

collections and those of the lower Grand River lies in the assumption of insufficiency of collections at Moab, which by chance failed to include a large number of the species of the Powell collection. In view of the fact that the collections from Moab and Sindbad Valley were made by several different collectors at different times, this explanation seems hardly a plausible one. Another interpretation is that there may be a stratigraphic break, due to uplift and erosion, through which the Aubrey strata found by Powell and Newberry have been removed at Moab, in the Sindbad Valley, and to the mountain region to the east. This implies that the Hermosa beds of Moab are present beneath the section examined by Powell and Newberry. Such a break must occur at the base of the Paleozoic "Red Beds," and no suggestion of such a hiatus has come from observations in Colorado; but it is to be remembered in this connection that in southern Utah and northern Arizona, Powell, Gilbert, Dutton, Walcott, and others have noted a persistent unconformity by erosion between the Aubrey and the succeeding strata now commonly referred to the Permian through Walcott's discovery of fossils in the Kanab Valley (**37**). All of the above-named geologists have observed a conglomerate more or less widely distributed at the base of the Permian series, composed in large part of pebbles derived from the Aubrey rocks, as shown by fossils contained in them. It is, of course, possible that the denudation at this horizon may have been much more extensive than the observations thus far reported would suggest. The situation is really not very different from that concerning the unconformity and stratigraphic break now known below the Dolores Triassic formation, which a few years ago was supposed to consist in comparatively slight unconformity by erosion.

The foregoing suggestion is in some degree confirmed by the fact, determined in the Colorado region, that the Hermosa fauna is succeeded by one having a distinct, and apparently a younger, facies (**16**, pp. 245–56), that of the Rico formation, which has not been found at Moab. Mr. Girty informs me that recent data tend to correlate Rico with the Aubrey formation (in part) through the Manzano group of New Mexico. In its lithologic, stratigraphic, and faunal relations the Rico is said to be suggestive of the Manzano group, which

in turn can be correlated with the Aubrey. The Manzano fauna comprises a certain number of species which occur also in the Rico, together with others not yet found in the Rico, which are more or less characteristic of the Aubrey.[1] There is also some confirmation of the relations thus suggested in the fact brought to my attention by Mr. Girty that the Hermosa fauna bears a noteworthy resemblance to that of the upper part of the Red Wall limestone of the Grand Canyon, while markedly different from that of the Aubrey. No great emphasis can be laid upon this at present, however, since the collections upon which Meeks' list of Red Wall forms given to Gilbert (**14**, p. 178) have been lost and further study of the Red Wall fauna is necessary to elucidate this matter. There is clearly a field requiring much further investigation as to the relations of the Red Wall, Aubrey, Hermosa, and Rico faunas.

THE PRE-CAMBRIAN COMPLEX

The ancient rocks of the Uncompahgre Plateau were described by Peale as in the main granites and gneisses with a subordinate amount of various schists. He called them Archean, considered them to be derived by metamorphism from sediments, and correlated them with the complex so well exposed in the Canyon of Gunnison River to the east (**29**).

There is every reason to suppose that the rocks in question do belong to the same great pre-Cambrian complex which is well known in other parts of Colorado. Our limited observations in Unaweep and West Creek Canyons and at other points indicate that the old rocks of the Uncompahgre Plateau are comparable in most elements with those of the Needle Mountains and the Gunnison Canyon. There are many gneisses and schists, the origin of which is not wholly evident. Some gneisses are granitic in composition and may plausibly be considered as mashed or sheared granite. But there are many very dark hornblendic schists and others containing both hornblende and biotite. Such gneisses and schists are probably the oldest rocks of the district and are naturally referable to the Archean.

The gneissoid and schistose rocks are cut by many bodies of coarse

[1] The relations of the Manzano group will be discussed in a forthcoming bulletin of the Survey by W. T. Lee and G. H. Girty.

or fine-grained granite, little modified by movement or pressure, and these seem plausibly to be equivalent in age to the massive granites of the Needle Mountains, which are later than the quartzites of the Uncompahgre formation referred to the Algonkian in the Needle Mountains and Ouray folios.

That the Uncompahgre quartzites are also present in the West Creek area is indicated by two observations. In West Unaweep Canyon, near the west end, a patch of white quartzite, some hunreds of feet in visible extent occurs on the north side of the valley a few hundred yards north of the road. Mr. Kay visited this outcrop and found it to consist of quartzite of fine, even grain, for the most part, if not wholly, surrounded by granite.

Another occurrence of quartzite was discovered by Mr. Woolsey within the area of Permian (?) sediments very near the granite line on the south side of West Creek and several hundred feet above the stream. These quartzites were surrounded and in part covered by the Permian (?) grits, and they apparently form a pinnacle or knoll which has been buried and is now again exposed by erosion. Small quartzite fragments were observed in the adjacent granite.

These quartzite occurrences, of which scarcely more than notice of their existence can now be said, are very suggestive in the matter of the correlation of the extensive Uncompahgre formation of the San Juan region with the still greater series of ancient quartzites in the Uinta Mountains. Both have been referred to the Algonkian and their similarity emphasized. The quartzites of West Creek are about 90 miles from the type locality for the Uncompahgre quartzites at Ouray on the north side of the San Juan Mountains, and 150 miles from the Uinta Mountains. They are thus so nearly intermediate as to add weight to the correlation suggested.

LIST OF PUBLICATIONS CITED

1. Boutwell, J. M. "Vanadium and Uranium in Southeastern Utah," *Bull. U. S. Geol. Surv.*, No. 260, 1904, p. 203.
2. Cope, E. D. "Report upon the Extinct Vertebrata Obtained in New Mexico by Parties of the Expedition of 1874." *Monographs, U. S. Geog. and Geol. Surveys West of the 100th Meridian*, Vol. IV, Pt. II.
3. Cross, Whitman. "Telluride Folio," U. S. Geol. Surv., *Geol. Atlas of the U. S.*, folio 57, 1899.

4. CROSS, WHITMAN. "La Plata Folio," U. S. Geol. Surv., *Geological Atlas of the U. S.*, folio 60, 1899.
5. CROSS, WHITMAN. "Rico Folio," U. S. Geol. Surv., *Geological Atlas of the U. S.*, folio No. 130, 1905.
6. CROSS, WHITMAN, and SPENCER, ARTHUR C. "Geology of the Rico Mountains, Colorado," *Twenty-first Ann. Rept., U. S. Geol. Surv.*, Pt. III, 1900, pp. 15–165.
7. CROSS, WHITMAN, and HOWE, ERNEST. "Silverton Folio," U. S. Geol. Surv., *Geological Atlas of the U. S.*, folio 120, 1905.
8. CROSS, WHITMAN, and HOWE, ERNEST. "Red Beds of Southwestern Colorado and Their Correlation," *Bull. Geol. Soc. Am.*, Vol. XVI, 1905, pp. 447–498.
9. DUTTON, C. E. "Report on the Geology of the High Plateaus of Utah," *U. S. Geog. and Geol. Surv. of the Rocky Mtn. Region*, 1880.
10. DUTTON, C. E. "Tertiary History of the Grand Canyon District," *Mon. U. S. Geol. Surv.*, Vol. II, 1882.
11. DUTTON, C. E. "Mount Taylor and the Zuni Plateau," *Sixth Ann. Rept. U. S. Geol. Surv.*, 1884–5, pp. 106, 198.
12. EASTMAN, C. R. "The Triassic Fishes of New Jersey," *New Jersey Geol. Surv., Ann. Rept. for 1904, 1905*, pp. 67–140.
13. ELDRIDGE, GEO. H. "Anthracite-Crested Butte Folio," U. S. Geol. Surv., *Geol. Atlas of the U. S.*, folio No. 9, 1894.
14. GILBERT, G. K. "U. S. Geog. Surv. West of the 100th Meridian," Mon. Vol. III, *Geology*, Pt. I, 1875, pp. 17–187.
15. GILBERT, G. K. "U. S. Geog. and Geol. Surv. of the Rocky Mountain Region," *Report on the Geology of the Henry Mountains*, 1877.
16. GIRTY, GEORGE H. "The Carboniferous Formations and Faunas of Colorado," *Prof. Papers, U. S. Geol. Surv., No. 16*, 1903.
17. HOLMES, W. H. "Report as Geologist of the San Juan Division," *U. S. Geol. and Geog. Surv. of the Territories*, embracing Colorado and parts of adjacent territories. Ninth Annual Report, for 1875, pp. 237–276, 1877.
18. HOWE, E. and CROSS, WHITMAN. "Glacial Phenomena of the San Juan Mountains, Colorado," *Bull. Geol. Soc. Amer.*, Vol. XVII, 1906, pp. 251–74.
19. HOWELL, E. E. "U. S. Geog. Surv. West of the 100th Meridian," Mon. Vol. III, *Geology*, Pt. III, 1875, pp. 227–301.
20. VON HUENE, F. "*Dystrophaeus viaemalae* Cope in neuer Beleuchtung," *Neues Jahrb. f. min. Geol. & Pal.*, Beilage, Band XIX, 1904, p. 319.
21. KING, CLARENCE. "U. S. Geol. Expl. of the 40th Par.," Mon. Vol. I, 1878.
22. KNIGHT, WILBUR C. "Some New Jurassic Vertebrates from Wyoming," *Amer. Jour. Sci.* 3d Ser., Vol. V, 1898, pp. 378–80.
23. KNIGHT, WILBUR C. "Jurassic Rocks of Southeastern Wyoming," *Bull. Geol. Soc. Amer.*, Vol. XI, 1900, pp. 377–88.

24. LUCAS, F. A. "Contributions to Paleontology," *Amer. Jour. Sci.*, 4th Ser., Vol. VI, 1898, pp. 399, 400.

25. LUCAS, F. A. "Vertebrates from the Trias of Arizona." *Science*, Vol. XIV, 1901, p. 376.

26. LUCAS, F. A. "A New Batrachian and a New Reptile from the Trias of Arizona," *Proc. U. S. Nat. Mus.*, Vol. XXVII, 1904, pp. 193–95.

27. MARVINE, A. R. "U. S. Geog. Surv. West of the 100th Meridian," Mon. Vol. III, Pt. II, 1875, pp. 189–225.

28. NEWBERRY, J. S. *Report of Expedition from Santa Fé, New Mexico, to the Junction of the Grand and Green Rivers of the Great Colorado of the West, in 1859*, Washington, 1876.

29. PEALE, A. C. "Report (as Geologist of the Grand River Division), U. S, Geol. and Geog. Surv. of the Territories," *Ninth Ann. Rept.* for 1875, 1877, pp. 31–101.

30. PEALE, A. C. "Report (as Geologist of the Grand River Division), U. S. Geol. and Geog. Surv. of the Territories," *Tenth Ann. Rept.* for 1876, 1878, pp. 161–185.

31. POWELL, J. W. "Some Remarks on the Geological Structure of a District of Country Lying to the North of the Grand Canyon of the Colorado," *Am. Jour. Sci.*, 3d Ser., Vol. V, 1873, pp. 456–465.

32. POWELL, J. W. *Exploration of the Colorado River of the West and Its Tributaries*, Washington, 1875.

33. POWELL, J. W. "Report on the Geology of the Eastern Portion of the Uinta Mountains and a Region of Country Adjacent Thereto," *U. S. Geol. and Geog. Surv. of the Territories*, 1876.

34. RIGGS, ELMER S. "The Dinosaur Beds of the Grand River Valley of Colorado," *Field Columbian Museum, Publication 60*, Geol. Ser., Vol. I, No. 9, 1901.

35. SCOTT, W. B. *Elements of Geology*, 1897, p. 477.

36. STANTON, T. W. "The Morrison Formation and Its Relations with the Comanche Series and the Dakota Formation," *Jour. Geol.*, Vol. XIII, 1905, pp. 657–669.

37. WALCOTT, C. D. "The Permian and Other Paleozoic Groups of the Kanab Valley, Arizona," *Amer. Jour. Sci.*, 3d Ser., Vol. 20, 1880, pp. 221–25.

38. WALCOTT, C. D. "Study of a Line of Displacement in the Grand Canyon of the Colorado in Northern Arizona," *Bull. Geol. Soc. Amer.*, Vol. I, 1890, pp. 49–64.

39. WARD, L. F. "Status of the Mesozoic Floras of the United States," *Twentieth Ann. Rept., U. S. Geol. Surv.*, Pt. II, pp. 217–430.

40. WARD, L. F. "Geology of the Little Colorado Valley," *Amer. Jour. Sci.*, 4th Ser., Vol. XII, 1901, pp. 401, 413.

NOTES ON THE GEOLOGICAL SECTION OF MICHIGAN

PART I. THE PRE-ORDOVICIAN

A. C. LANE and A. E. SEAMAN
Houghton, Mich.

INTRODUCTION

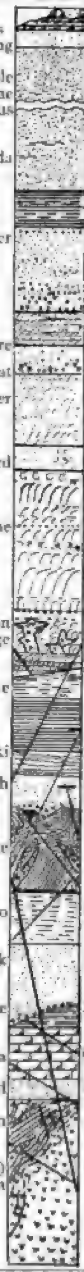
It is not as easy to summarize the section of Michigan as, for instance, a compact state like Iowa. For one thing the state is so spread out that, turned around by its southeast corner on the map, it would reach beyond New York into the Atlantic Ocean, and turned around by its northwest corner, would extend to Hudson's Bay and into the Dakotas. Again it includes within its borders representatives of probably the oldest land masses, which have been frequently, if not continuously, above sea level ever since they were first elevated. The geological succession may therefore be expected to be interspersed with beds laid down on land and in lakes fresh and salt, and seas like the Caspian and Black, by stream and wind, as well as wave.

Part I includes the pre-Trenton rocks which even the drill has not reached in the Lower Peninsula.

In preparing these notes the state geologist had assistance from Professor Seaman of the College of Mines as to the older rocks to such an extent that it may be best expressed by joint authorship. Indeed what he knows of the Upper Peninsula is so interwoven with what he has learned from and with Professor Seaman that anything he could write would be essentially of that nature.

With regard to the Paleozoic series he has had the advantage of the constant assistance of Mr. W. F. Cooper, and of unpublished reports by A. W. Grabau and N. H. Winchell to examine. Since, however, he differs quite materially from Dr. Grabau, and Dr. Grabau has recently given elsewhere[1] the essential features of his interpretation, no detailed reference to these unpublished reports will

[1] *Bulletin Geological Society of America*, Vol. XVII, p. 567.

System	Series Name	Formation Name	Columnar Section	Thickness	Character of Rocks
Ordovician		St. Peter		0 to 75	*Sandstone;* white, waterbearing, in hollows of Calciferous dolomite, but absent often
		Calciferous		255 to 180	Buff and bluish dolomites often sandy, with dolomitic white sandstones.
		Munising		200	*Sandstone;* white or light, waterbearing.
	Neo-Cambrian Saratogan (Potsdam)	Lake Superior: Jacobsville Redstone		0 to 1500+ (4000?)	*Sandstone:* red and brown and striped with streaks of red clay shale, conglomeritic where it laps upon older formations.
		Hiatus		not drawn to	scale, the relation of the Freda to the Lake Superior Sandstone being uncertain, probably one formation.
	Upper Keweenawan, perhaps	Freda		(900+)?	*Sandstone:* red, with some felsitic and basic débris, and salt water.
	Mio-Cambrian	Nonesuch		350 to 600	*Shales:* dark, fissile beds, with dark basic fragments, and products of decomposition of lavas copper-bearing.
		Copper Harbor: Outer		1000 to 3500	*Conglomerate:* very heavy, red, with large rounded bowlders of all lower formations including jaspilitic iron ores, agate amygdules, gabbro aplites, etc.
		Lake Shore		1800 to 400	*Traps:* basaltic lavas, and at least one—the "Middle"—conglomerate.
Cambrian or Primordial		Great		2200 to 340	*Conglomerate:* very heavy, like the outer conglomerate.
	Keweenawan	Eagle River		2300 to 1417	*Group* of basic lava flows with *frequent* beds of sediment, Marvine's (c).
	Lower Keweenawan, perhaps eo-Cambrian	Ashbed		1456 to 2400± (50 sediment)	*Group* of basic lavas of the "ashbed" type with scoriaceous sediment and only 50 feet or so of conglomerate. Locally felsites.
		Central Mine		3823 to 25000? (480 sediment)	*Group:* mainly of lavas of the augitic ophite type, with infrequent sediments. At the top is the "Mesnard epidote" and just beneath the heaviest flow, over 1 000 feet thick at times known as the Greenstone. Under this is the Allouez conglomerate, Marvine's No. 15. No. 13 is the Calumet and Hecla conglomerate or lode. The Kearsarge Lode is shortly above 9.
		Bohemian Range		? to 9500+ (500 sediment)	*Group:* mainly of basic lavas but with intrusive and effusive felsites and coarse labradorite porphyrites; also intrusive diabase dikes and gabbro and gabbro aplites.
	Animikean neo-Huronian	Michigamme		1000 to 4000	*Slates:* black and graphitic, and graywacke slates, passing into graywacke arkoses, and quartzites; metamorphosed into staurolite, chiastolite, garnet, and other mica schists and phyllites.
		Bijiki		300 to 800	*Iron formation or schist:* slates with cherty carbonate and soft ore.
		Goodrich		0 to 400+	*Quartzite;* with conglomerate base, and above quartzite or red and green flags, also volcanic material.
		Negaunee		1000±	*Iron formation:* cherty carbonates, altered to jaspilites, etc., with effusives and intrusives altering to hornblende schists and amphibolites.
	Mio-Huronian	Siamo		600±	*Slates:* graywackes and arkoses and volcanics.
Huronian		Ajibik		700±	*Quartzite.*
		Wewe		300±	*Slate:* black largely.
	Eo-Huronian	Kona		600±	*Dolomite:* with siliceous cherty and slaty (schistose) bands.
		Mesnard		250±	*Quartzite:* conglomerate and arkose, becoming a seriate schist or gneiss.
Laurentian		Kewatin (Marinescan) = Laurentian		1000+	Greenstone schists, amphibolites, hornblende schists, sericite schists or crushed felsites, rarely ellipsoidal greenstones and slates and jaspilites, very largely cut by granites, the Laurentian, and numerous other classes of injections.

be necessary. It need not be said that there are many things and many divisions in the geological column upon which further light could be thrown, and it is hoped that before long the Paleozoic geology of the Upper Peninsula may receive more careful attention. But it is the state geologist's feeling that it is well to be sure one is right before going ahead in any change of names, since any such change renders reports less readable even to the geologist, much more so to the teacher, engineer, and others who make casual use of them. This is much more the case when a number of new names are brought in at once. In regard to the scientific questions involved, see the article, "The Geologic Day," *Journal of Geology*, 1906, p. 425.

One general remark should be made. The point of view of the state geologist is largely that of a student of well records and of the drillings returned from them, in which the fossils play next to no part. Not only is the point of view of Dr. Grabau that of a paleontologist, but this must also be remembered, that the study of the paleontologist on outcrops is, in a broad and general way, the study of formations nearer their margins and more likely to be of some other type than simply marine, and if marine deposits, more likely to be deposits of the littoral, and of extreme transgression.

In studying and comparing well records it is a notable fact that certain parts of the geological column seem to be persistent and easily correlated from well to well. Others vary markedly, even in extremely short distances. These are the points where the unconformities come in.

The columnar section is divided into two parts, on different scales, since the thicknesses of the pre-Ordovician units are much greater than those of the later ones. The thicknesses in the column are those derived from wells where the formation is as flat as possible and as far removed from its source. An attempt has been made to draw the column to scale, giving each formation something like its minimum thickness when not obviously cut off by erosion, unconformity, or overlap. The numbers placed along the side, however, show also the customary range up to the greatest thickness of which we can be reasonably sure. Still greater thicknesses may and often have been estimated, but in our judgment may not have had due allowance made for faulting, initial dip, or crushing.

The Laurentian-Keewatin.—These terms we take to have the same stratigraphic meaning, since the relations are of intrusive contact—the former being applied where the areas are largely feldspathic or granitic and light colored, the other when they are mainly of basic rocks, or klastic in a good many cases, of the nature of volcanic tuff (the "Greenstone schist" or "Mareniscan"). In Michigan at least there is comparatively little if any of the commoner types of sediment and limestones, either in their altered or unaltered condition. Many of the schists which are fine grained and slaty enough to pass for altered sediments prove really to be altered felsites, or volcanic ash, or something of that kind. There is, however, a little iron-ore-bearing jaspilitic chert and rarely genuine black slates. Early conditions of erosion before there was any land vegetation would have led to the formation of arkoses and tuffs, and there may have been less ocean of a very different chemical character, accounting for the scarcity of ordinary types of sediment. Generally speaking these rocks are more or less saturated with granitic matter, either in fine-grained aplitic or coarse-grained pegmatitic veins, but the whole rock may be a gneissoid granite. These gneissoid granite bosses generally occupy anticlinal areas, and are the typical Laurentian. Around Marquette there seems to be a compound synclinal with argillites in the upper part and some ill-defined iron-bearing beds which may correspond to the Vermilion Range below, and a great deal of "Greenstone schists." These latter consist of hornblende and chlorite schist and amphibolites, including rarely "ellipsoidal greenstones," and sericite schists altered from felsites throughout, but especially in the lower parts next to the granitic anticlinal bosses. The total thickness one can estimate not less than 1,000 or more than 5,000 feet.

By Bigsby, Maclure, etc., this formation was grouped as gneiss or granite with the hornblende slate under the term primitive; by Houghton and his assistants as syenite, granite, gneiss under the term primary; by Logan as Laurentian; by Foster and Whitney as granite rocks of the Azoic period; by A. Winchell as granitic rock of the Plutonic group; by Credner as the Lower Laurentian of the Eozoic; by Brooks and Pumpelly and many others following them as Laurentian; by Rominger as Huronian; by Van Hise and the

U. S. Geological Survey as Archean (the basement and fundamental complex); by Wadsworth as the Cascade formation. Yet a glance at the various geological maps of Lake Superior shows that, however different the connotation, or meaning, and the theories of the various writers as to relationships, the areas and rocks *denoted* were mainly the same.

Of other terms the "Mona" series is referred to by Foster and Whitney (p. 35), in the European sense, similar, but probably not identical, with the sense of the term used in the *Marquette Monograph*. That and "Kitchi" are intended to be synonymous terms, but include some areas of extra highly metamorphosed Huronian.

The term Mareniscan (*Van Hise Monograph*, 19, p. 473), appears to be a later synonym of Keewatin and it was decided by the joint committee to prefer the latter, but should further discoveries make a local Michigan term needful, may be used, as Wadsworth's term Cascade is later and included, we believe, disparate things. The "Palmer gneiss" appears to be a sheared facies of some of the Huronian members up to the Siamo slate. It is only fair, however, to be ready in regard to so difficult a group as the earliest rocks, to accept a term even though there be some slight inconsistency or error made by the author, provided only that they are not so great as to destroy its usefulness by making uncertain its general application.

Huronian.—The name under which the pre-Cambrian rocks have been assembled in this state has varied. Among the earliest writers who derived their information from direct observation was Credner, then Professor Pumpelly's assistant, who published a paper in Volume II of this survey, and whose thesis for the doctorate was on *Die Gliederung der eozoischen (vorsilurischen) Formations-Gruppe Nord-Amerikas*[1], which is, as far as I know, the first original work published after that of Foster and Whitney. Douglass Houghton's "metamorphic" rocks were in the Huronian. Foster and Whitney, in spite of themselves, divided the formations to be considered, classing them all as Azoic, into granitic rocks (chap. iii); iron ores and associated rocks (chap. iv). Credner calls them all Eozoic, and divides them into Huronian and Laurentian, and the same divisions are used by Brooks and Pumpelly. As between the terms Azoic and

[1] Published at Halle, 1869.

Eozoic, Proterozoic, Archeozoic, and Archean, we are not prepared to give a final decision, but find the usage of Chamberlin and Salisbury convenient. The terms Laurentian and Huronian have been used pretty continuously in the Lake Superior region, and always with almost the same practical application, so far as this state is concerned. We think, therefore, that we should in them follow Credner and Logan. It is at present agreed to divide the Huronian into three series. A question may arise whether the lowest of these series, which is considerably older than the other two, more eroded, and quite different in distribution, may not be the Grenville or Upper Laurentian. There is, however, no local ambiguity involved, as it has always been mapped with the Huronian in this state.

Eo-Huronian.—We use this term in preference to Lower Huronian, as that was applied to the eo-Huronian and mio-Huronian until the threefold division of the "Marquette" series was recognized. The *Marquette Monograph* calls it Lower Marquette. We had always called it Mesnard (formation or series).[1] The U. S. and state survey now restrict this name to the basal member.

a) Mesnard quartzite. Well exposed on Mt. Mesnard just south of Marquette, finely ripple marked, with about 250 feet of slaty flags toward the base, which is a conglomeritic and arkose quartzite.

There are also brecciation beds, slate, quartzite, and cherty quartzite toward the Kona dolomite above.

It is at times much metamorphosed and sheared and may be confounded with underlying beds, and is at times cut by granites, but by no means as commonly as the Keewatin. We think, too, the granites cutting the Huronian have a different character, being much more inclined to a coarse porphyritic facies.

b) Kona dolomite. This is a very well marked horizon around Goose Lake, but is represented, we believe, on all the ranges and in the original Huronian, being the Randville dolomite of the Menominee Crystal Falls region, and the Bad River formation of the Gogebic Range.[2] But extensive erosion took place before the deposition of the mio-Huronian, generally removing the slates above it and often cutting deep into the dolomite........................600 ft.

[1] *1892 Report*, p. 65.

[2] Rominger's "Marble" Series, Vol. IV, p. 56.

c) Wewe slates. The slates of Goose[1] Lake, rarely left by the erosion, but exposed on Carp River, Sec. 5, T. 47 N., R. 25 W., and on Sec. 12, T. 47 N., R. 26 W., black and gray slates........300 ft.

Mio-Huronian.—This we are inclined to believe is the main iron-bearing formation, not only of the Marquette range, but of the Menominee range as well. During this time began an epoch of basic volcanics at numerous points which continued into the neo-Huronian and expressed itself mainly in intrusives altered to amphibolite ("diorite"), chloritic schist, "paint rock," and uralite diabase in the mio-Huronian, and mainly in effusives and tuffs in the neo-Huronian.

This is Van Hise and Leith's Middle Marquette; compare also Wadsworth's "Republic" and "Negaunee" formations.[2]

a) Ajibik quartzite. Has often been confused with Mesnard quartzite. Grades upward through slaty phases into *b*)......700 ft.

b) Siamo slate. Grits, flags, and graywackes, and graywacke slates, with volcanic tuffs..................................600 ft.

c) Negaunee formation. The main formation of cherty carbonates and siliceous beds with "greenalite" readily altering into jaspilitic iron-bearing formation..........................1,000 ft.

Near igneous contacts it also changes into grünerite, and other amphibole-magnetite schists.

Neo-Huronian (Animikie).—The relations of this series around Port Arthur on the north side of Lake Superior and along the Gogebic range on the south are such, both as to the overlying and underlying rocks, that there can be but little doubt that they are in general coeval, and the graphitic slate horizon of the upper part seems to be widely identified. We have no hesitation in adopting the term Animikie. There may be some question as to whether it belongs in the Huronian at all. We believe Lawson considers the greatest and most profound unconformity[3] to come at the base of this formation, rather than for instance, between the Mesnard and the Keewatin or

[1] *Wewe* is Chippewa for "goose."

[2] Though he was never quite able to agree with what seems to us the proper interpretation of the stratigraphy of the same, so that the order as given on p. 66 differs so much from our views that we could hardly use it without producing confusion. See *1892 Report*, pp. 64, 66, 110, etc.

[3] The Eparchean interval.

greenstone schists, and it must not be forgotten that the Minnesota Survey has held it to be Cambrian.[1] Were the Gogebic range alone to be studied we might agree with Lawson, but there the unconformity at the base of the Animikie represents the elimination of all of the mio-Huronian and most of the eo-Huronian, thus representing a good part of Huronian time. Without question the Animikie is much less disturbed than the older formations, but we are not prepared to say that any one of the breaks before the Keweenawan is the "essential break."[2]

The divisions are:

a) Goodrich quartzite. This is represented on the Gogebic range by the Palms formation of red and green quartzose slates. But there, as on the Marquette range, there is a conglomerate base, containing pebbles of jaspilite and dolomite as well as granite. Basic tufaceous material is a sign of local volcanic activity, which continued from mio-Huronian (part of Clarksburg formation, etc.) near foci of which the formation may be very thick. Otherwise..........400 ft.

b) Bijiki formation. This is a cherty, iron-bearing member with graphitic slates, on the Gogebic range some 800 feet thick, known as the Ironwood formation and the main iron member. It was not considered in the *Marquette Monograph* so persistent as we really believe it is ....300 ft.

c) Michigamme slate. A group of black, graphitic slates and graywackes, quite wide spread—the Tyler slate of the Penokee-Gogebic range, the Lake Hanbury slates of the Menominee Range. Usually not over 1,000–2,000 feet thick. On the Gogebic range apparently.. 4,000 ft.

Keweenawan.—This term used as a technical name for a rock series is nearly synonymous with Nipigon, which has a year or so priority, but was introduced practically simultaneously in two slightly different senses; and the term Keweenawan has been so much more widely used that the joint committee agreed to retain it. Douglass Houghton included the Lower Keweenawan up to the Great Con-

[1] But Logan and Hunt in the original introduction of *Huronian—Esquisse Géologique*, p. 28—considered Huronian as Lower Cambrian of Sedgwick. But at that time, as in the earlier editions of Dana, the Potsdam was classed as Silurian.

[2] Leith in *A. I. M. E. Trans.*, 1906, p. 128.

glomerate under the general head "Trap rocks" and understood that "strictly in their chronological order" they came after the "metamorphic" slates and quartz rock. The Lake Shore traps were thought of as intrusive dikes, so that he could group the Greater and Outer Conglomerate together under the head "conglomerate" and the rest of the Keweenawan as "mixed conglomerate and sand rock." Foster and Whitney followed his divisions in their mapping, including them as the lowest divisions of the Silurian (which, as in the early editions of Dana, was understood to go down to the Azoic and include the Primordial) and as intimately associated with the Lake Superior sandstone, so much so as not to need any separate formation name. It has already been mentioned that the latter has been referred to various ages from Triassic back. Logan called them the "Upper copper-bearing" rocks; Brooks and Pumpelly the Latin equivalent "Cupriferous," and considered the formation conformable to the Huronian, but covered unconformably by the Lake Superior sandstone, and likely to be more allied to the former than the latter. Irving introduced the term Keweenaw(an), and in ***Monograph V***, p. 24, recognized an unconformity (disconformity) of the Keweenawan and Huronian, as well as an unconformity above, especially with the Mississippi Valley Cambrian sandstones. Neither of the unconformities do we doubt. But they appear to be with basal Keweenawan beds disturbed by coeval volcanic activity and faulting, and seem to us quite comparable with inter-Keweenawan phenomena, while the Lake Superior sandstone and the Upper Keweenawan appear to us closely associated not merely lithologically but stratigraphically.[1] We prefer, therefore, for the present, to place the Keweenawan in the Cambrian to express that fact. If we could but be sure that there was indeed a universal cycle of sedimentation and rhythm of geological activity, by which, all the world over, crustal rearrangements and volcanic activity took place simultaneously, while at other times atmospheric conditions universally favored the deposit of limestones or black shales, there would then be more of a temptation to compare our column with the type column in Great Britain and see in the Longmyndian red sandstone and volcanics .... the correlates to the Keweenawan.

[1] See *Annual Report*, Board of Geological Survey of Michigan, 1904, p. 143.

Longmyndian flag stones and shales and Rushton schists	....	the correlates to the Animikie black slate and graywackes.
Bradgate, Beacon Hill and Black Brook hornstones of Charnwood Forest	....	the correlates to the Huronian cherts and jaspilites.

The Keweenawan would then indeed be pre-Cambrian. But far-off lithological correlations have too often proven a will-of-the-wisp.

Lower Keweenawan.—The conglomerates which occur at the top of the Lower Keweenawan and below the Lake Shore traps may perhaps belong stratigraphically to the Upper Keweenawan. They contain a wide variety of pebbles and large bowlders, and are in structure at times suggestive of till.

The main part of this formation cannot at its thinnest point be put down as much less than 15,000 feet. Its base in contact with the upper beds of the Animikie formation has recently (H. L. Smyth) been found north of the Gogebic range. Here its thickness appears to be near 42,500 feet, and I do not think it can possibly be reduced by any allowance for repetition by faulting and initial dip to less than 29,000 feet. Some such thickness of rock with the specific gravity of trap over against an equal thickness of granitic rocks would be needed to produce isostatic equilibrium between the bottom of Lake Superior and the Huron Mountains. Of this thickness only a small fraction is sedimentary and that of a type which may be rapidly accumulated, so that the whole series is not necessarily of great duration. The general characteristic of the lavas which made it up is that, while they run from silicious felsites and quartz porphyries to quite basic rocks, there is nothing ultra basic nor ultra alkaline known. Porphyritic crystals are mainly quartz and feldspar. These have normally crystallized earlier in the magma. A marked second generation of augite is almost unknown. When we come to estimate how much of it is sediment, however, we find that continuous diamond-drill sections would indicate for the major part of it less than 7 per cent. (5.65 per cent. in 8,500 feet, 6.65 per cent. in the 6,247 feet at Isle Royale). The greater the thickness probably the less the per centage. Making detailed allowance for the Great and certain other

heavy conglomerates at the top, we get 4,250 feet for the sediments alone—conglomerates and sandstones of very rapid deposition for the most part. A detailed section is given in the *Black River Report*, Annual for 1906, p. 400. Fairly persistent (Isle Royale, Black River, Keweenaw, Mamainse) appear to be the following divisions of the Keweenawan from below:

1. *Bohemian range group* (Irving's (1) and (2), Plate XVII) characterized by numerous flows of labradorite porphyrite type and felsites near the top and frequent intrusions, of straight-walled diabase dikes, of felsite, of gabbro and affiliated red rocks, or gabbro aplites. North of Bessemer, the thickness, igneous sills included, is ....9,500 ft.
There may not be 500 feet of sediment.

2. *Central (Mine) group.*—Including the "Greenstone group," the "Phoenix Mine group," etc., but only a part of Pumpelly's "Portage Lake series," and just about that part included and well exposed in the workings of the Central mine on a cross-fissure, exposing a good section, examined by Pumpelly and Hubbard, and more recently supplemented by diamond-drill cores on the same property (sections 24, 25, 36, T. 58 N., R. 31 W.). This is a new name we would introduce and define as extending from the Bohemia conglomerate, Marvine's conglomerate (3) or (8) to the "St. Mary's epidote," a sediment, volcanic ash, just above the "Greenstone" and Marvine's conglomerate (15). Characterized by very heavy flows of ophite, some of them hundreds of feet thick, so that, for instance, the "Greenstone," the one at the top of the series, extends beneath Lake Superior, from one side to the other; often proportionately coarse grained.

On Black River there are possibly 25,000 feet including flows. At Portage Lake (7,882), say 8,000 feet.

3. "*Ashbed*" *group.*—This group has been named from the Ashbed Mine, or really originally from a lode so called by the miners, worked at that mine, Marvine's (*a*) and (*b*), Irving's (5) and (6). Including conglomerates 16 to 18, characterized by frequent glomerophyric that is relatively feldspathic and fine grained flows.

In the Tamarack shafts............................2,400 ft.

The amount of well-marked conglomerate is not over 50 feet but

the amygdaloids shade into beds of scoria mixed with red mud called "ashbeds."

4. "*Eagle River*" *group*.—Marvine's (*c*), characterized by waning volcanic activity shown by numerous (10 or more) sandstones and conglomerates, while the interbedded flows are more of the normal type. In the upper 2,300 feet Marvine estimates 860 feet of sediment. On Black River it is given as 1,417 feet; at the Tamarack as 1,700 ft.

5, 6, and 7. *Copper Harbor conglomerates*.—The conglomerates north of the Eagle River Group were grouped together by Douglass Houghton, who considered the Lake Shore Traps as intrusive dikes. When these were understood to be interbedded flows, the conglomerate was divided into the Great and Outer, respectively, below and above the Lake Shore traps. Hubbard's studies around Copper Harbor have shown that there are at least three heavy conglomerates. It is not probable that the lines between the Great Conglomerate, Lake Shore Trap, and Outer Conglomerate can be drawn at all consistently. Together they cover the period of decadent vulcanism, and it is not at all likely that the flows from these last expiring throes filled the whole basin but more likely they occur irregularly in the conglomerate series. It therefore seems fitting to give a local term to the whole assemblage, treating the Lake Shore traps as a lentil or lentils in the same.

5. "*Great*" *conglomerate*.—Its thickness, not allowing for initial dips, is say 2,200 feet at Eagle River and Calumet, but apparently much less, 340 feet, on Black River. It has a wide variety of pebbles, but mainly of Keweenawan rocks.

6. *Lake Shore Traps*.—These are apparently thickest near Copper Harbor where using Hubbard's figures, they are about 1,800 feet thick. They are near 900 feet thick at Calumet, but at Black River are only about 400 feet thick. There is at least one well-marked conglomerate in the group. Above this group is the line between the Upper and Lower Keweenawan as drawn by Irving, marked by a cessation of volcanic activity. There are also less dips in general, and very soon a greater variety in detritus.

7. *Outer conglomerate*.—With pebbles representing all the Lower Keweenawan types, including intrusives, amygdules and agates, and also the Huronian jaspilites. Only 1,000 feet are given at

Keweenaw Point, but to the Nonesuch shale on Black River it must be much thicker, not allowing for initial dip at least 3,500 feet. Irving estimates 3,000 feet in the Porcupines.

8. *Nonesuch formation* (from the Nonesuch mine).—Dark colored shales and sandstones—owing its dark color to the basic material—a very significant sign of heavy erosion of Keweenawan traps at some distance. This seems to be a very persistent horizon in lithological character, in spite of not being very thick, being 600 feet on the Porcupines, 500 feet on Black River, and 350–400 on the Montreal.

9. "*Freda sandstone.*" "Main body of sandstone" or "western sandstone" of Rominger (*not* Irving). This seems to need a local name and may well take it from the new stamp-mill town on the shore of Lake Superior, not far from Portage Lake Canal, near which exposures occur, and a well showed a thickness of over 970 feet of sandstones and shales. The relation of this to the "Lake Superior sandstone" in general is a mooted question. It was included in it by early writers. It is much like it lithologically and structurally though felsitic and basic débris and streaks of red clay may be rather more common and the water more saline than in the Lake Superior sandstone around Marquette. The one mantles a granitic boss from which the other was separated, as the Nonesuch shale shows, by extensive exposures of Lower Keweenawan.

Wells in unquestioned Lake Superior sandstone at Lake Linden and Grand Marais show that it is 1,500 feet and over thick. The dips are generally less than those of deposition, so that we cannot make much use of them. Irving estimates the thickness at 12,000 feet, but this is, we believe, based solely on the questionable Montreal river section. We do not, however, think, that it will be decreased below 4,000 feet, if we allow 1,500 feet to the Lake Superior sandstone and make 8,000 feet for the whole upper Keweenawan. We repeat that we are not at all sure that there is any other than an arbitrary dividing line between it and the sandstone which we propose to call Jacobsville.

Lake Superior sandstone.—This term was used by Houghton, and has been customary since, the term Sault Ste Marie sandstone being much later and less used. It is often and quite properly called the Potsdam. It is necessary only to refer to the supposed equivalence

with the "New red" Triassic sandstones, held by Jackson, Marcou,[1] and for a time Bell. But accepting its approximate equivalence and even continuity with the Potsdam, there still may be a question as to its exact horizon, which can not be exactly the same everywhere, and might be widely different. It is readily divided in outcrop and in wells into a redder and lower portion and a whiter upper portion. The line between the two may mark the epoch of submergence of the iron-bearing rocks, only a few islands of granite and quartzite, remaining exposed to erosion. In view of the uncertainty of the relation of the three parts of the Lake Superior sandstones, as used by Houghton, separate names seem to us likely to be useful, and we propose not only the term Freda sandstone for that west of the Copper Range, but the term Jacobsville (from Jacobsville where the famous quarries of Portage redstone occur) sandstone for that east of the Copper Range, and we suppose this term may apply to all the Lake Superior sandstone skirting the coast at intervals to Grand Island, while the term Munising sandstone is to apply to the upper 250 feet of Lake Superior sandstone which crosses the bluffs back of Munising, dips southerly, and is white or light colored. Houghton considered the upper "gray sandstone" (700 feet ?) to be unconformable on the lower, dipping south to southeast, while the lower dips to the north. The upper part is well ripple-marked, cross-bedded, friable, with *Fucoides* (?) *duplex* and *Lingulepis prima*, and *L. antiqua*. *Dikelocephalus misa* (?), *Dikelocephalus* (Hall, Pl. XXIII, 3*a*–*e*, 4), and *Lingulepis primiformis* occur at Iron Mountain which Walcott told Lane was of the Ptychaspis zone. At Marquette Murray reports *Pleurotomaria laurentina* (?) and Scolithus and beds similar at Campment d'Ours close under the Trenton. At Limestone Mountain, below the fairly extensive Trenton fauna, are some conglomeritic beds before we come to the main mass of sandstone. Logan (followed by Grabau)[2] mainly on the strength of the (en)Campment d'Ours Island section concludes that the Lake Superior sandstone may "represent the Chazy, Calciferous, and Potsdam." Beside the Campment d'Ours Island section the Neebish well also indicates a great thinning of the section below the Trenton to the pre-Cambrian along St. Mary's river. But the question remains whether it is by a dis-

[1] *Bull. Geol. Soc. Trans.*, Vol. XXXII, p. 102.

[2] *B. G. S. A.*, Vol. XVII, pp. 582, 617.

conformity and erosion of the Calciferous and St. Peter's down to the Lake Superior sandstone, so that at least most of the sandstone below the "Trenton" limestone is Cambrian and represents the Lake Superior sandstone generally, or whether this sandstone represents the St. Peter's sandstone, the "Potsdam" and Calciferous having been overlapped, or the latter by a shoreward change of facies passed into a basal sandstone, which might represent continuous transgression of the ocean. The St. Peter sandstone is well marked at the Wisconsin line, with a good 200 feet of Calciferous (Lower Magnesian dolomite) under it and also, as records just arrived show, at intervals along Green Bay, at least as far as Rapid River. The Calciferous certainly continues as a thick, well-marked formation well beyond Calciferous station and creek, and according to Rominger clear to T. 45 and 46 N., R. 1 W., and Neebish (Anebish) Rapids. Moreover a few scattered wells to rock as at Newberry in the center of the peninsula do not record any St. Peter's. All these facts favor the first interpretation independent of the fact that it seems to fit better with Berkey's interpretation of the St. Peter sandstone, though to be sure it implies a disconformity at Campment d'Ours Island.[1]

As has been said the total thickness of this sandstone and the extent to which it is equivalent to the Freda and Upper Keweenawan sandstone are conjectural. As it laps upon the areas of older rocks its thickness diminishes to nothing, and there is often a conglomerate at its base. Its composition is largely quartz and feldspar of the acid varieties, sometimes up to 37 per cent. of orthoclase and microcline. The absence from the formation, except immediately at its contact with other formations, of much basic or even a large amount of felsitic débris which is more abundant in the Upper Keweenawan, is one of the reasons why we believe there can be no great discordance or time interval between this and the Upper Keweenawan. It seems to mark the culmination of the same general depression, when only the granite cores were exposed and finally even these were covered. The upper sandstone which Houghton called the "gray sandstone" he estimated at 700 feet thick. Wells indicate only some 250 feet. The change may indicate that the transgression had gone so far as practically to bury any iron-bearing rocks.

[1] Cf. Rominger, Vol. I, Part 3, pp. 64, 76, 77, 82, and 83.

Calciferous formation.—This formation appears to have been called by Houghton the sandy limerock, and was said to occur at several points on Sailor's Encampment Island (not Campment d'Ours) near West Neebish Rapids. On Foster and Whitney's map of Lake Superior it was called the Calciferous, a name which it has since generally retained (Winchell's map, 1865, Brooks, Pumpelly, and Rominger's map 1873, and the state survey since, *U. S. G. S. Monograph 36*, 1899, etc.), and has indeed become imbedded in the local nomenclature of Calciferous Creek, a branch of the Au Train river, and Calciferous, a station on the Marquette and Southeastern R. R., so that it may be retained even as a geographic name. "Lower magnesian limestone" has from time to time been used as synonymous. The Hermansville limestone of the *Menominee Special Folio and Monograph*, pp. 31, 494 (Bayley, 1900–04) is this formation, or some part of it. It is given as not over, but near to, 100 feet thick, and equivalent to the Chazy and Calciferous of the east on Rominger's authority. The wells along the Green Bay shore, however, show a fairly constant maximum thickness of about 250 feet. Here flowing wells reach the Lake Superior sandstone between 600 and 700 feet. A late record from Marinette shows, however, 75 feet of white sandstone at the top which may be a trough filled by St. Peter sandstone. The interesting record is in brief:

Quaternary sand	69– 69
Galena and Trenton	256–325
Blue and brown limestones and dolomites	
Sand at 260′, red shale at 290′ (St. Peter horizon ?)	
St. Peter (?)	
White sandstone	75–400
Calciferous	
Brown dolomite	60–460
White sandstone	70–530
Dolomite (Hermansville)	50–580
Lake Superior sandstone	
Upper, white sandstone	195–775
Lower, pink, shading into conglomerate of cherty quartzite, base uncertain	95–870
Huronian	
Cherty quartzite ?	108–978

It looks as though thus close to the Archean land mass the formations were much broken by unconformities and sandstones (of course allowance must be made for imperfect records), and perhaps the term Hermansville will be fittingly applied to the lower 50 feet of the Calciferous. We may compare the triple division of the Calciferous, with the Shakopee dolomite, New Richmond sandstone, and Oneota dolomite of Minnesota.

11. *St. Peter sandstone.*—Outcrops of this have never been identified in Michigan. But the Green Bay wells show a constant water-bearing horizon at about the level where it should appear, and occasionally sandstones, or red clays, and residual dolomites. At this formation we break the column. It is the top of that part exclusively known or seen in the Upper Peninsula. It marks a break which Rominger and others considered the important break which should mark the top of the Cambrian.[1]

[1] See Berkey, *B. G. S. A.*, Vol., XVII, pp. 229–50.

NOTES ON THE JAMAICA EARTHQUAKE

MYRON L. FULLER
United States Geological Survey, Washington, D. C.

INTRODUCTION

The following notes on the Jamaica earthquake are based upon observations made by the writer during a visit to Kingston in March, 1907, and upon interviews with government officials and others who were present in the city at the time of the disaster. Special thanks are due to Mr. Robert Simmons, A. I. C., of the Government Laboratories for information furnished, and to Mr. F. G. Clapp of the United States Geological Survey, who was associated with the writer in his studies and who has supplied several of the photographs accompanying the present paper. Owing to the shortness of the stay at Kingston the observations were of necessity somewhat limited, and no claim for completeness can be made, the object of the paper being simply to present some of the more important results of the earthquake as observed by the writer or described to him by eye-witnesses.

The city of Kingston is located on the south side of Jamaica, on the seaward edge of a large alluvial fan, occupying a V-shaped re-entrant in the mountains. In front of it is a spacious harbor, separated from the open sea by a long sand-spit, stretching westward for a distance of eight miles from the mainland, at a point about four miles southeast of the city. The relations are shown in Fig. 1.

GEOLOGY

The island of Jamaica consists essentially of an east-west core of metamorphosed Cretaceous shales, conglomerates, serpentine limestones, etc., standing at high angles and cut by granitic intrusions, surrounded by a narrow belt of younger and less disturbed Cretaceous sands, marls, and limestones, around which in turn is a wide belt of Eocene limestones, etc., with a few patches of Neocene around the edges. The structure is anticlinal, the trend of the uplift being from a little north of west to south of east. A considerable number

of faults occur with trends parallel to the structural ridge while others are approximately at right angles to it. Large alluvial fans are found in indentations of the mountains at many points.

TOPOGRAPHY

In a general way the topography depends on the geologic structure, the mountainous areas corresponding with the upturned meta-

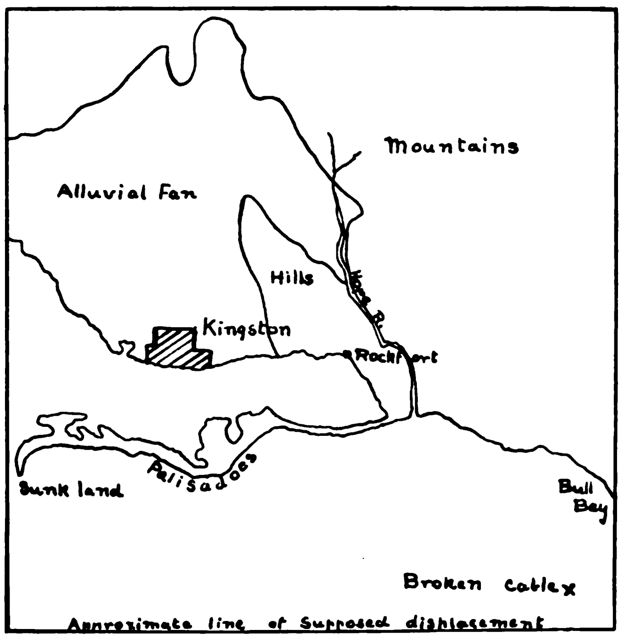


FIG. 1.—Sketch map illustrating location and surroundings of Kingston, Jamaica.

morphic tracts and the broad plateaus bordering the mountains, especially to the west, coinciding with the younger and less disturbed Eocene beds.

GENERAL SEISMIC CONDITIONS

Seismic disturbances have been of frequent occurrence in the island of Jamaica since its settlement, but in general the shocks have been of slight intensity. In 1692, however, an earthquake of great severity took place, engulfing such parts of the city of Port Royal as were built upon the sand-spit across the harbor opposite the present

site of Kingston, and seriously damaging smaller areas built on the limestone reef. In the 200 years following this great shock the island was shaken from time to time by minor disturbances, some of which were of some intensity, but no record seems to have been kept until the latter part of the last century. The records available to the writer[1] covered the period from February 19, 1880, to November 25, 1906, during which 163 shocks were felt. Their distribution, which is shown in the accompanying table, indicates a maximum in the autumn and winter months with a minimum in the spring and summer months. The activity shown in the last column is computed by assuming that two shocks of Intensity I are equal to one of Intensity II, and that two of Intensity II equal one of Intensity III. In other words, I equals one, II equals two, III equals four, IV equals eight, etc.

From the table it will be noted that the activity is 198 in the night hours (6 P. M. to 6 A. M.) as compared with 150 in the day (6 A. M. to 6 P. M.). The principal activity is from 2 to 5 o'clock in the morning with a lull at daybreak followed by a marked increase in the activity from 7 until 9. From 9 until 1 there are very few shocks, but from 2 to 4 the number is again high, after which it drops to a very low point from 5 to 7 o'clock. In the evening there is a strong rise between 8 and 10 o'clock, after which there is a falling off until the 2 to 4 o'clock period the following morning. This early morning period of activity (2 to 4 A. M.) corresponds with one of the minima of the diurnal variations of barometric pressure. The forenoon period of low activity, from 9 to 11, corresponds with the forenoon maximum; the afternoon period of intensity, from 2 to 4, with the corresponding barometric minimum. Up to this point the disturbances agree with that postulated by the advocates of greatest activity during barometric minima with least activity during the maxima. The evening period of barometric maximum, which according to theory should be a period of minimum activity, however, is in reality one of great activity, while the least activities of all are found at daybreak and sunset when theoretically they should be of intermediate activity. These variations are not confined to the Jamaica earthquake, but have characterized others, especially the New Madrid earthquake of the Mississippi Valley in 1811, the record of the shocks of which

[1] Maxwell Hall, published in the local press, February 18, 1907

were carefully kept during the period of disturbance, which lasted over a year. The table of these shocks shows nearly the same features throughout as the tabulated data above. Just what the factors are which give rise to the peculiarities of distribution are not known, but they appear to be of a general rather than a local nature.

SEASONAL DISTRIBUTION OF JAMAICA EARTHQUAKES, 1880–1906

	I	II	III	Activity
Spring (March, April, May)	21	10	1	45
Summer (June, July, August)	16	11	1	42
Autumn (September, October, November)	41	11	2	71
Winter (December, January, February)	35	9	5	73

DIURNAL DISTRIBUTION OF EARTHQUAKES

Based on 163 shocks previous to November 25, 1906, and 90 shocks after that date

Hour	I	II	III	Activity
12 M.	7	2	1	15
1 A. M.	3	3	1	13
2 A. M.	11	5	2	29
3 A. M.	13	9	..	21
4 A. M.	8	2	..	12
5 A. M.	9	5	..	19
6 A. M.	7	1	..	9
7 A. M.	12	3	1	22
8 A. M.	10	1	..	12
9 A. M.	5	3	..	11
10 A. M.	6	..	..	6
11 A. M.	7	..	..	7
12 M.	9	2	..	14
1 P. M.	6	2	..	10
2 P. M.	9	3	1	19
3 P. M.	4	4	2	20
4 P. M.	7	2	..	11
5 P. M.	5	2	..	9
6 P. M.	5	1	..	7
7 P. M.	6	1	..	8
8 P. M.	4	4	1	16
9 P. M.	11	1	1	17
10 P. M.	12	4	1	24
11 P. M.	9	1	1	15

Of the disturbances preceding the principal shock, that occurring in November, 1906, was the most severe, rattling dishes, shaking a few bottles, etc., from shelves, and producing slight cracks in a few instances, being a stronger shock than any subsequent to the main disturbance.

THE RECENT EARTHQUAKE

WEATHER CONDITIONS

At the time of the recent severe shock, which occurred a little after half-past three in the afternoon, the barometer stood at 29.551, which is normal for the locality and elevation. The weather was clear. The shock occurred near the date of the new moon at which period, it is claimed by some, the Jamaica earthquakes are particularly likely to occur, owing to the supplementary attraction due to the conjunction of sun and moon. A comparison with the table above also shows that it took place near the afternoon period of maximum intensity.

TIME AND DURATION

The principal shock, which was the only one producing any serious damage, took place at 33 minutes and 6 seconds past 3 o'clock in the afternoon of January 14, 1907, and lasted about 30 seconds. The vibrations were not of uniform strength, but were marked, according to descriptions, by at least three recurrent pulsations of alternating low and high intensities.

CHARACTER OF MOVEMENT

Direction of vibrations.—Those who experienced the shock in Kingston are generally of the opinion that the vibrations were along an east-west line, but whether from the east or from the west there is some disagreement. That the principal movement was along the line indicated is further attested by the fact that the east and west ends of buildings were most commonly thrown down, east and west walls more frequently buckled and crushed, and cracks in the walls mainly in east and west directions. As will be seen later the epicenter was very near Kingston, and there was more or less deflection of the waves by the surrounding mountains, doubtless giving rise to complications of movement which more or less disguised the normal direction of transmission.

Nature of vibrations.—The nature of the earth movements depended largely upon the character of the underlying material at the point where the shock was observed. On the solid rocks and on the compact semi-cemented alluvium on which Kingston is situated the

movements were of the short, sharp, tectonic type, there being practically nothing in the nature of the undulatory surface wave. At Port Royal, on the other hand, the surface waves predominated,

FIG. 2.—Southward facing statue of Queen Victoria, twisted in anti-clockwise direction by tortional movements. (Photo by Fuller.)

the ground rising and falling as the movement progressed in the same manner as do the waves upon the sea.

The seismographs were put out of commission at the beginning of the shock, and for the nature of the shock personal observation must be depended upon. According to the accounts of those who were interviewed by the writer, the first vibrations seemed to come

from below, the action somewhat resembling in effect the feeling one might experience if the floor on which one was standing were subjected to a hard blow from underneath. This was apparently followed by a rapid motion from side to side, and finally by a tortional motion which is described as shaking objects much as a terrier shakes a rat. It was this motion which produced the twisting exhibited by nearly all statues in the city (Fig. 2). As already indicated, there were three or more maxima of intensity during the shock. A feeling of intense confusion was experienced by those feeling the shocks but nausea was seldom produced.

Intensity and amplitude of the vibrations.—The amplitude of the vibrations appears to have been small. Only in occasional instances were street cars shaken from the tracks, few of the statues were overturned, and only a small number of telegraph, telephone, or trolley poles were overthrown or tilted. This would hardly have been the case if the lateral movement had been considerable. As nearly as can be judged from descriptions the movement was not over an inch.

The intensity of the shock, as attested by the ruins, however, was very high, the destructions being to a considerable extent due to a sort of disintegration, apparently resulting from very strong and rapid vibrations, which, however, were of short amplitude, at least in the rock areas and the stiff semi-compacted alluvium of the Kingston region.

ASSOCIATED PHENOMENA

Noise.—The earthquake was accompanied by a loud noise, described as a deep crushing sound, somewhat suggesting distant thunder but with less boom and more of a roar. Intermixed with the natural sounds proceeding from the earth was the crashing of the buildings and the cries of the people, the two together being described as almost deafening.

Dust.—One of the phenomena described by all eye-witnesses was the notable darkness following the shock. The local mortar, rather poor at the best, which was used in most of the buildings, pulverized quickly, and was projected into the air together with other dust in immense quantities as the buildings fell, saturating the atmosphere until it was almost impenetrable to the suns rays. After the cessation

of the shock it slowly settled, covering everything with a thick white mantle of fine calcareous silt.

EFFECT ON INHABITANTS, ETC.

Behavior during earthquake.—The greater part of the inhabitants of the island of Jamaica are negroes or mulattoes, although a very considerable number of whites reside in the cities, especially in Kingston and Port Royal. The negroes, although Christianized, retain

FIG. 3.—Wreckage in area of severe disturbance. In places the ruin was so complete that streets could be traced only with difficulty. (Photo by Cleary's Studio, Kingston.)

many of their superstitions and are very demonstrative, a fact which had an important bearing on their behavior and attitude during and subsequent to the earthquake. The very first shock threw them into the greatest fright, but it was far from a paralyzing fright either as regards speech or motion, for the majority fled precipitately from their houses into the streets and open places as a howling mob, alternately screaming and praying, sometimes, it is said, both at once. Even after the vibrations had ceased the excitement and noise continued for some time, and the greatest confusion prevailed. The police and troops were soon out, however. and the wrecked district

was carefully patrolled, no one without a pass being permitted to enter. Throughout the shock the whites behaved with a considerable degree of calmness, being without the unreasoning fear which characterized the blacks, yet none could reach the open too soon. Animals, wherever not thrown down by the shock, generally stampeded, horses, mules, and cattle being alike in this respect.

Loss of life.—The loss of life on the island, as compiled from identified remains and the list of missing, is officially given as 1,003, almost the whole number of casualties being at Kingston or vicinity. The high death list resulted from the fact that the shock occurred late in the afternoon when the stores and sidewalks were full of people. The loss in some of the stores was very large, that in the "Beehive," "Army and Navy," "Waterloo House," and "Croswell's" being greatest. From 25 to 40 sometimes lost their lives in a single store. At the Jamaica Club 7 out of 9 were killed, while in other buildings, like the Colonial Bank, everyone escaped. Many lost their lives upon the sidewalks, crushed by the falling buildings. The loss was greatest in Port Royal Street, Water Lane, and vicinity, which was one of the most completely wrecked districts, the position of some of the streets being hardly distinguishable amidst the rubbish after the shock. Few people in this vicinity escaped uninjured. So great was the destruction and accumulation of débris that at the time of the writer's visit, two months after the shock, bodies were still being recovered from the ruins.

Outside the city and vicinity the loss of life was not great, although a few people among the mountains were killed by falling rock or landslides. Of the deaths many were instantaneous, but many persons were caught in the ruins and burned in the conflagration which followed the shock. Twenty or thirty died subsequently from blood poisoning resulting from improperly dressed or neglected wounds. No epidemic of sickness has yet appeared.

EFFECT OF EARTHQUAKE

The results of the earthquake varied considerably according to the nature of the material constituting the surface at a particular point. Rock areas, alluvial fan deposits, and sand-spits are the principal types involved.

ROCK AREAS

Land slides.—The rock areas near Kingston are confined principally to the mountains, the narrow border of coastal plains being of unconsolidated materials. In the rock areas the surface is composed of

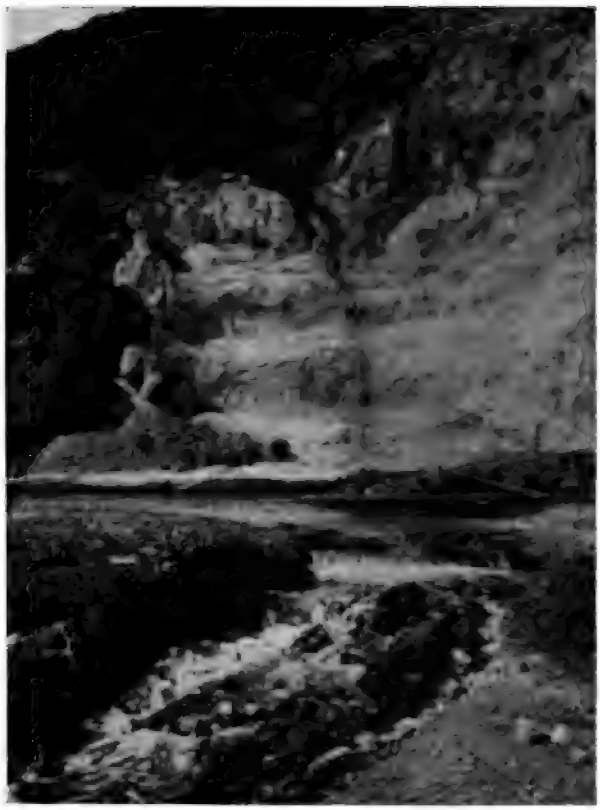


FIG. 4.—View of large spring (400 gallons per minute) resulting from rock fractures in soft limestone at Rockfort quarry. (Photo by Fuller.)

disintegrated rock, bowlders of disintegration, etc., forming a mantle or talus over the hillsides. The slopes in many instances are very steep, and as a result of the earthquake many bowlders and avalanches were precipitated down the mountain sides, leaving great bare scars on their faces. In many cases trails were obliterated and roads ruined by slipping or by coverings of débris and, as already mentioned,

a few people were killed. In the large government quarry at Rockfort east of Kingston large pieces of the walls were broken down forming large heaps of débris.

Outbreak of springs.—Previous to the earthquake a single large spring had flowed from the limestone at the base of the quarry at Rockfort, but at the time of the shock a second spring, as large or larger than the original, broke forth through fractures produced at the time and flowed to the sea as a stream between three and four feet wide, five or six inches deep, and with a velocity of several feet per second. The water is salty and slightly thermal, and at times is said to be somewhat sulphurous.

ALLUVIAL DEPOSITS

Character.—The alluvial deposits, upon which Kingston was built, consist mainly of a gravel with a stiff, reddish, sandy clay matrix, binding the whole into a somewhat tough resistant mass. Geologically it belongs to a broad alluvial fan occupying a re-entrant in the mountains and rising from sea level at Kingston to an elevation of several hundred feet at the base of the mountains. Throughout the fan, except near its seaward edge, the ground water is rather deep and had but little effect on the phenomena of the earthquake, the material behaving, in fact, much like solid rock, being almost entirely without the warping, fissures, etc., such as usually characterize unconsolidated materials.

Earthquake fissures.—From the fact that the movements were of the nature of vibrations rather than visible earth waves it was not to be expected that fissures would be produced to any extent upon the mainland. In fact, it was only near the margins of stream gullies and along the sea margin—points where there was an opportunity for lateral displacement—that fissures were formed. Of the displacements along stream banks, those near the Hope Culvert were among the most pronounced, the aqueduct bearing a part of the city water being broken by the movement at this point. Along the water front the fissures were more numerous. Near Victoria Market, especially, a considerable number of small fissures parallel with the sea margin were formed, from which considerable amounts of sand and water were extruded. The latter, however, were from no great

depth as the water level is here within a few feet of the surface. The locality on the mainland where the cracks are most numerous seems to be east of the city between the end of the trolley line and the government quarries at Rockfort. At this point the shock was not

FIG. 5.—Earthquake cracks due to lateral displacement toward the sea, near Rockfort, Kingston. (Photo by Fuller.)

only more severe, but the road built on an artificial shelf at the water's edge and only five feet above it, offered especially favorable conditions for fissuring. Cracks were observed along this road for a distance of half a mile. Some were less than five feet in length and only about one inch in breadth, while others up to one hundred feet or more and with a width up to four inches were noted. Most of the cracks were irregu-

lar gaps, originally extending downward to the level of the sea from three to eight feet below. An interesting feature, however, was presented by the absolutely straight and regular fissures, sometimes fifty or more feet long, and determined by the line of excavation made

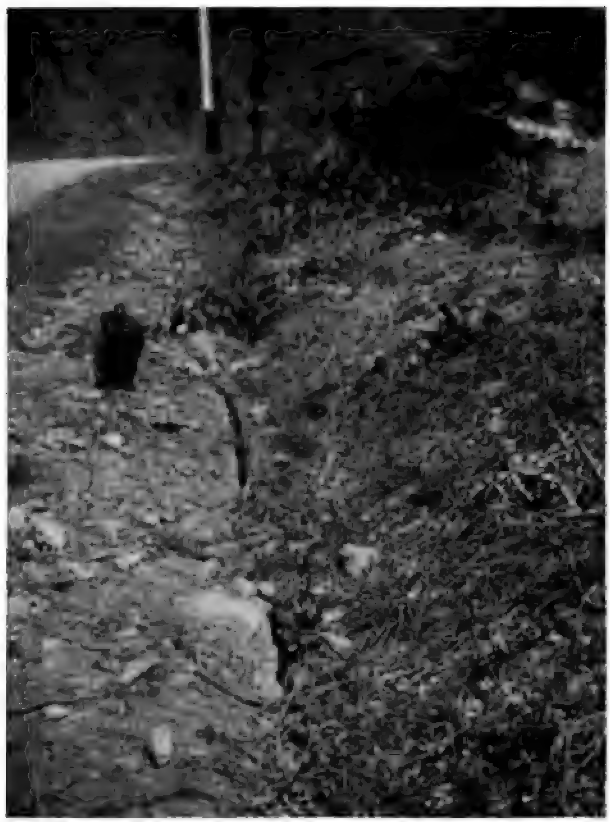


FIG 6—Earthquake crack due to lateral displacement along line of old sewer excavation. (Photo by Fuller)

years before for the sewer. In all cases the fissures were parallel to the water front and resulted from the separation of a narrow strip along its margin, generally slightly displaced and somewhat tilted toward the sea.

Faulting.—Very little faulting took place in the alluvial deposits,

although slight displacements took place along some of the fissures. In one instance near Rockfort the road along the shore seemed to have fallen with reference to the sidewalk a distance of four to six inches, and at other points a sinking of the road of from one to two feet, doubtless owing to flowage of the underlying sand, seems to have occurred. In other cases the motion appeared to be the reverse, the segment containing the sewer sinking with reference to the road.

Extrusion of sand and water.—As already mentioned more or less sand and water was extruded from fissures near the water front at the Victoria Market, but, owing to the toughness of the alluvium, the depth of the water table, and the absence of large earth waves, the conditions were unfavorable for such action. No craterlets were reported, and there appears to have been no extrusion from the cracks along the Rockfort road as described above.

Change of level.—No noticeable change of level of the land, except in the fissured and slumped zones at the immediate margin of the sea has been recognized. So far as can be determined the water stands at the same level along the wharves as before the shock.

SAND SPIT (PALISADOES)

Extending from the mainland about four miles east of Kingston a long spit known as the Palisadoes stretches westward, a distance of eight miles, forming the harbor of Kingston. Patches of reef limestone representing original islands, reach the surface of the spit at at least two points. With the exception of these rocks the entire mass is composed of loose wave- and wind-drifted sands, standing only a few feet above sea level and saturated with water nearly to the surface. The conditions for the propagation of earth waves and for disintegration and slump were, therefore, far more favorable than in the tough alluvial deposits at Kingston, and, as would naturally be expected, the destruction was much more severe. On the limestone patches, on the other hand, the action was similar to that on the mainland.

Fissures and extrusions.—Fissures and extrusions of sand occurred at various places on the Palisadoes, especially near the point of connection with the mainland. Here long lines of closely spaced faults parallel to one another and to the sea margin were formed. The

displacements of the individual faults was usually only from six inches to a foot, but the aggregate displacement amounted to many feet. Along some of the fault lines large quantities of sand and water were extruded, the points of emergence being now marked by long narrow craterlets. More or less fissuring and extrusions of sand are also said to have occurred at the end of the point at Port Royal, the cracks apparently opening as the crest of the earth wave advanced and closing (accompanied with the extrusion of sand and water to a height of several feet) as the crest gave way to the following trough. Most of this action was on the part of the point which finally sunk below the sea (Fig 7.).

Tilting and warping of surface.—Owing to the same incoherent nature of the materials there was not complete recovery from the earth waves, the surfaces at many points remaining in the form given them as the waves progressed. An even more important effect, however, appears to have been produced by the flowage of the saturated sands. The result of the two was to leave the surface bent and warped, a condition brought out strongly by the present attitudes of the artificial structures. Near the end of the point, as one enters the harbor, a wooden tower is observed tilted several degrees and the gun foundations equally out of level. On the inside of the point the sea wall is likewise tilted at a considerable angle, and one of the wharves is similarly inclined. Several of the flagpoles are much inclined and numbers of houses noticeably tilted, while in one case the middle of a building seems to have sunk several feet with reference to the ends, breaking it from bottom to top along the center. The railroad tracks at one point are reported arched up for a distance of twenty-five yards, the elevation of the center above the ends being estimated at about four feet, while lateral twists in the tracks were not uncommon. In some localities arches in the surface with angles from 3° to 10° are said to occur.

Subsidence and submergence.—The tilting and warping described in the last paragraph resulted from differential movement, parts of the surface being lifted while other parts sunk. In many instances the subsidence was sufficient to bring the bottom of the cellar below the level of the ground water so that water now stands above their floors. At one point on the north side of the Palisadoes the sinking

was such that a lagoon formerly separated from the salt water by a beach twenty yards in width and two or three feet high was covered by the sea. Perhaps the most conspicuous change of level was at the extreme south-west point of the Palisadoes at the entrance of the harbor, where a body several hundred feet in length and breadth sunk beneath the waters of the ocean. Fig. 7, which represents a view of this point, shows the palm trees and shrubs, still upright,

FIG. 7.—Submerged land at southwest termination of the Palisadoes at Port Royal. (Photo by Fuller.)

projecting from the water. The subsidence, which here seems to have been from ten to twenty feet, was probably due to a sort of flowage of the loose water-saturated sands underlying the surface at a depth of a few feet. A mangrove swamp on the harbor side of the Palisadoes is reported to have sunk ten feet.

In addition to the cases mentioned, what may possibly be a case of subsidence was seen from the steamer off Morant Point at the east end of Jamaica, some forty miles from Kingston. The shore at this locality is low for some distance, only a narrow strip of beach

showing between the water and the forest which here comes to the shore. In a few places this beach, as seen from a distance of not over a mile, seemed to be missing, the water reaching amongst the trees, the foliage of which appeared to be dried and withered as if recently killed by a subsidence which had admitted the sea.

EFFECT ON SEA BOTTOM

Kingston harbor.—Immediately following the earthquake many stories were circulated as to the obstruction of the harbor by mud flows, etc., but soundings in its channel showed that it had not been materially altered and vessels of deep draft soon entered and left as usual. Inasmuch as the bottom is prevailingly soft, and as the soft materials at Port Royal were much disturbed, there was doubtless much flowage wherever the bottom possessed any considerable inclination. The action was most marked, along the shores of Port Royal, where the bordering bottom sunk many feet in places, accompanied by a corresponding rise at a point farther out, or by at least an outward flowage of the soft deposits.

Sea bottom off coast.—On the sea bottom there appears, on the contrary, to have been disturbances of great magnitude, the center being, it is stated, some three or four miles off shore at a point southeast of the mouth of Hope River at the east end of the Palisadoes where they are attached to the mainland. In this locality the bottom is reported to have been decidedly roughened by movements of its soft materials, resulting in the breaking of the cable at points from three and one-half to fifteen miles off the coast. Several miles were so twisted, broken, or buried that new cable had to be laid. No such action occurred anywhere on or near the land, and, if accounts are to be relied upon, this is to be regarded as the region of greatest disturbance.

EFFECTS ON FORESTS

The action of the Jamaica earthquake on forests was relatively slight. On the mountains a few insecurely rooted trees were more or less tilted and some dead trees are reported to have fallen. The chief destruction, however, was by avalanches which not infrequently made paths many feet wide for several thousand feet down the mountain sides. On the Palisadoes and in similar situations where the

surface caved or sunk beneath the sea, many trees were submerged and killed by the salt water. The possible submergence of considerable areas in this way at Morant Point was suggested on a previous page.

EFFECT ON ARTIFICIAL STRUCTURES

Kingston

The intensity of the Jamaica earthquake was very great and the destruction correspondingly severe, the ruin apparently being equal to, if not surpassing, that in the Charleston and San Francisco earthquakes in our own country. While some high buildings escaped complete demolition, nearly all were badly wrecked, while in many cases even the one-story houses and stores were destroyed. The destruction was not uniform, however, varying greatly according to the nature of the materials used in construction. In the order of their resistance the structures were of steel, wood, stone, concrete, and brick.

Brick structures.—In the brick structures some of the most interesting forms of destruction were exhibited by the posts forming parts of the fences found in front of a great number of houses. The usual method followed in the construction of the fence was the erection at intervals of from ten to fifteen feet of square brick posts, about one and one-half feet in diameter and five or six feet tall, between which iron or wooden picket fences were placed. When the vibrations struck the fences the brick posts were in 90 cases out of 100 broken off at their base, falling en masse at right angles to the fence, especially where it ran in a north-south direction. In several instances the brick posts were thrown out of the fence, leaving the wooden palings standing. On the east-west streets the posts were sometimes thrown toward each other, crushing the wooden or buckling the iron fences between. Besides the destruction of the posts en masse some were disintegrated by the shock, the bricks of the center being loosened and causing a marked bulging. A few more vibrations and the whole would have crumbled.

The destruction of the brick garden walls was also severe, everything over 3 feet in elevation being generally badly injured. On north-south streets there was a tendency to fall en masse, while in

east-west streets, tortional warping, disintegration, and the breaking away of large chunks was common.

FIG. 8.—Wrecked church tower. Note clock stopped at 3:35. The tower has since fallen. (Photo by Cleary's Studio, Kingston.)

The action on brick buildings was variable. The better class stood in some cases through both shock and fire, although the motion was sufficient to snap flagpoles at their tops. The churches fared very badly, most of them, even where not completely demolished, being practically ruined, the damage being such that they had to be pulled down (Fig. 8). The fact that they had little interior strengthening in the way of partitions probably contributed to this result. The cracks generally meandered irregularly, but approximately diagonally through the brick walls, commonly making an angle of about 45° with the horizon. In other cases the action seemed to be largely one of disintegration, the latter being assisted by the rather poor local mortar commonly used. In general the destruction on the north-south streets seemed more complete than in the east-west streets.

Stone structures.—There were relatively few stone structures in the city or vicinity. Of these the Government Laboratories, several miles away, were almost unaffected, only a few small cracks, not necessitating repair, being developed. At the Colonial Bank, composed of stone and brick, the destruction was greater, but none of the occupants was killed, while many in surrounding brick buildings lost their lives.

Cement structures.—Only one cement structure was seen by the writer. This was the building of the Jamaica College, situated near the Government Laboratories just mentioned. Unlike the latter, however, it was so badly wrecked that a portion had to be pulled down and the whole practically rebuilt. The action was one of cracking rather than of disintegration. The cement was not reinforced to any extent.

Wooden structures.—The frame houses were considerably wrenched and twisted by the shock, and their plastering was often cracked or shaken down, but, owing to their elasticity, they generally escaped demolition, and after cleaning and a few repairs were ready for reoccupancy. A few wooden buildings were wrecked, however, in the eastern part of the city where the action was especially severe.

Steel structures.—There were no steel office buildings in the city, but two markets, the Victoria on the water front (Fig. 9) and a similar one near the public square were built mainly of this material. They

were little affected by the shock, presenting almost no outward signs of disturbance, although the former was near the water's edge where the ground was much agitated and small fissures opened. They were still usable after the shock.

Combination buildings.—The type of dwelling having a lower story of brick and an upper story of wood was very common at Kingston, but was, unfortunately, not adapted to resist the earthquake disturbances. The brick portion was invariably damaged and in a

FIG. 9.—Showing complete demolition of brick tower while wooden porches are unaffected. (Photo by Cleary's Studio, Kingston.)

great many cases collapsed completely, the wooden upper part often resting on the ground, its integrity essentially preserved, presenting a striking lesson in the relative resistances of the two materials.

Windows.—One of the striking features of the earthquake was the few windows which were broken. In many instances the window frames, without a single pane broken, were seen where the brick walls surrounding them had crumbled and fallen. This immunity seems to indicate that while there was much shaking there was relatively little tortional or crushing movements in the walls. The peculiar feature of window panes perforated by clean-cut round holes,

but not otherwise shattered, were also a striking feature, apparently resulting from bricks or other objects thrown laterally with considerable velocity by the shock.

Curbings and pavings.—In general there was no disturbance of the curbings or pavements in the city. While possibly some occur, none was seen in the dozen or more streets examined by the writer, except a small crack across the pavements at the Victoria Market, said to be due to the shock.

FIG. 10.—General view of ruins in fire district, Kingston, showing absence of disturbance in curbing. (Photo by Fuller.)

Reservoirs and water mains.—The reservoirs and water mains were somewhat disturbed, but not greatly so. The reservoir near Constant Springs was somewhat cracked, and the aqueduct at Hope Culvert broken and a part of the water supply cut off. The mains were rarely appreciably damaged.[1]

Railroad tracks and fixtures.—The steam-railway tracks were

[1] The failure to get water during the fire was due largely to the burial of the hydrants by débris and injury to the engines by falling walls.

practically unaffected, and trains could be run with little difficulty almost immediately after the shock. On the Atlas Wharf, however, the tracks were warped slightly and had to be relaid. In the city a few trolley poles appear to have been titled by the shock, although the greater part were bent by falling débris. In the country few trolley or telegraph poles were affected, generally remaining upright even where near the sea. The sway of the poles seems to have been considerable, nevertheless, many of the wires being snapped, especially in the district east of the city.

Rockfort District

Rockfort is the name applied to the old fort at the government quarries on the coast some three miles east of Kingston. A number of artificial structures were disturbed in this region, principally between the fort and the small stream entering the harbor beyond the old Naval Pier half a mile west of the quarry. At the mouth of the stream mentioned the cement culvert was much damaged, a part being buckled up and faulted (Fig. 11) while other parts were precipitated into the stream. At the same point the gutter was faulted downward several inches along the edge of the sidewalk. It is interesting to note in Fig. 11 that the wooden house, although near the region of greatest disturbance, is little affected.

Along the water front near here the sewer, a large iron pipe, was broken by the shocks, presumably by a buckling in the deposits.

Port Royal

Owing to the failure to get a permit to visit the fort the observations were mainly made from the water. The wooden tower at the southwest terminus is tilted 4 or 5 degrees from the perpendicular. One of the wharves on the harbor side appears to have been tilted toward the land at a considerable angle, the outer end being several feet higher than the inner. A railroad track was arched for a distance of twenty-five yards, the center being four feet above the ends. The sea wall was disturbed and tilted. Many buildings were severely wrenched and partially wrecked, the fact that the damage was not greater being due to the fact that they were of the frame type. One building was noted broken in two where the middle had sagged owing to a depression formed beneath it while the two ends remained elevated.

ATTENDANT FEATURES OF THE EARTHQUAKE

Tidal wave.—Kingston has an inclosed harbor one to two miles in width and five or six miles long, protected from the open sea, except at its mouth at the western end, by the long sand-spit or Palisadoes upon which Port Royal is located. Even the entrance is partially protected by reefs rising nearly or quite to sea level. It is to this fact that Kingston owed its immunity from tidal waves, except those generated within its harbor. These were relatively small, although large and powerful enough to throw one vessel up into the

FIG. 11.—Sidewalk arched and faulted by lateral movement of the walls of a culvert toward the stream. Also illustrates the slight damage to wooden structures. (Photo by F. G. Clapp.)

mud alongside the dock, while another, the Royal Mail Steamer "Arno," barely escaped wrecking by being thrown against the wharf.

Considerable waves were reported at sea, and one sufficient to move small buildings situated near the beach came ashore at Port Antonio on the northeast side of the island. Judging from the fact that the damage is no greater than it is at Port Royal, it is evident that the waves reaching shore at this point were of no great size. A large wave would have washed over the entire point, sweeping everything before it.

PROBABILITY OF FUTURE EARTHQUAKES

The earthquake of 1692 was much more destructive than the one of the present year. It was followed by a long period of relative quiescence, but with sufficient minor shocks to show that the readjustment was not complete until another great slip resulted in the shock of Jamaica, which, together with the subsequent tremblings, show the same is still true of the present time. A temporary local readjustment has, however, probably been reached, but although another severe earthquake may not occur in the near future, destructive shocks will almost certainly occur at some time in the future.

CAUSE

The writer believes the earthquake of January 14 to be due to a displacement along an east-west fracture probably not over three miles in depth at a point three or four miles south of the city, the greatest movement being at a point about four to five miles southeast of the city of Kingston. The disturbance is regarded as probably resulting either from isostatic readjustments or to fracture under the accumulated stresses due to processes of folding or uplift. The reasons are as follows:

1. The direction of movement along the south coast in the vicinity of Kingston varied from southeast-northwest to southwest-northeast, apparently indicating a long line of disturbance rather than a localized center, the position of the fracture being to the south and hence beneath the sea. Movement along such a fault explains the variation of direction of propagation of the vibrations near Kingston, and the tortional movement so characteristic of the later vibrations.

2. The area of greatest disturbance extended from the eastern part of Kingston to Bull Bay, some miles beyond the base of the Palisadoes, as shown by the more severe action on buildings, the greater frequency of fissures, the more profound disturbances in the rocks (as evidenced by the breaking out of springs), by the more frequent prevalence of faulting, fissures, craterlets, and warping in the Palisadoes, and especially by the profound disturbances of the sea bottom leading to the breaking of the cable at a point three and one-half miles southeast of the mouth of Hope River and the base of the Palisadoes.

3. The sharpness and intensity of the vibrations seem to be such as would characterize shocks arising from rock fractures rather than from disturbances due to the slipping of unconsolidated deposits on the inclined sea bottom as suggested by Dr. J. W. Spencer.[1] The shock was distinctly felt by the seismographs at the Weather Bureau at Washington, D. C., the amplitude of movement being about one-fiftieth of an inch, which it is believed would hardly have been the case if due to a landslide in superficial deposits.

4. The elevation of the east end of Jamaica, near which the faulting occurred, is about 7,400 feet, while the sea to the south is approximately 18,000 feet, making a total difference in level of over 25,000 feet. It can easily be conceived that isostatic readjustments, such as would tend to take place wherever such differences of level exist, at closely adjacent points, might have given rise to the fracture. It may be noted in this connection that each of the heavy earthquakes occurring in the western hemisphere in the last year—San Francisco, Valparaiso, Jamaica, and Mexico—all took place in regions of similar sharp differences in elevation. On the other hand, all are in regions characterized by more or less recent distortion, as brought out by the elevated beaches, warped and faulted beds, etc., and folding must be regarded as a possible source of the stresses giving rise to the fractures.

[1] J. W. Spencer, *Science*, N. S., Vol. 25, 1907, pp. 966, 967.

GLACIAL EROSION IN LONGITUDINAL VALLEYS

FRANK CARNEY
Denison University

The recent papers of Professor Sardeson[1] and Mr. Campbell[2] on folds in surface strata, the former within and the latter without the glaciated region, suggest the publishing of some analogous observations made in Owasco Lake (New York) valley.

Two questions will be considered in this paper: (1) Did overriding ice produce the folds, and, (2) if so, what bearing does this disturbance of subjacent strata have in the question of glacial erosion? The localities concerned are shown in Fig. 1, which is a transfer of a portion of the Moravia Quadrangle, omitting the 20-foot contour intervals. Owasco Lake lacks one-fourth of a mile of reaching the northern margin of this sheet. Its former higher levels extended several miles southward, as described in the papers of Watson[3] and Fairchild,[4] these higher levels being marked by numerous deltas. Southward from Locke the valley branches about a salient which reaches an altitude of 1,500 feet. The inlet stream rises some thirteen miles south of the present lake in an outwash plain near Freeville. The rock topography suggests a former divide between Locke and Groton.

DESCRIPTION OF THE FOLDS

The overturned fold shown in Fig. 2 is located on the map, Fig. 1, by station 2, northeast of Locke. The cross-section of the fold is nearly perpendicular and is oriented S. 30° E.; its axis has a tilt of approximately 51°. The disturbed layers are fourteen inches thick, consisting of thin, sandy shale, very much disintegrated. These layers overlie a sandstone bed six inches thick, below which are heavier layers used for building-stone. The disturbed strata are

[1] *Journal of Geology*, Vol. XIV (1906), pp. 226–32.

[2] *Ibid.*, Vol. XIV (1906), pp. 718–21.

[3] *N. Y. State Museum, 51st Ann. Rep.*, Vol. I (1897), pp. 792–94.

[4] *Bull. Geol. Soc. Am.*, Vol. X (1899), pp. 49, 50.

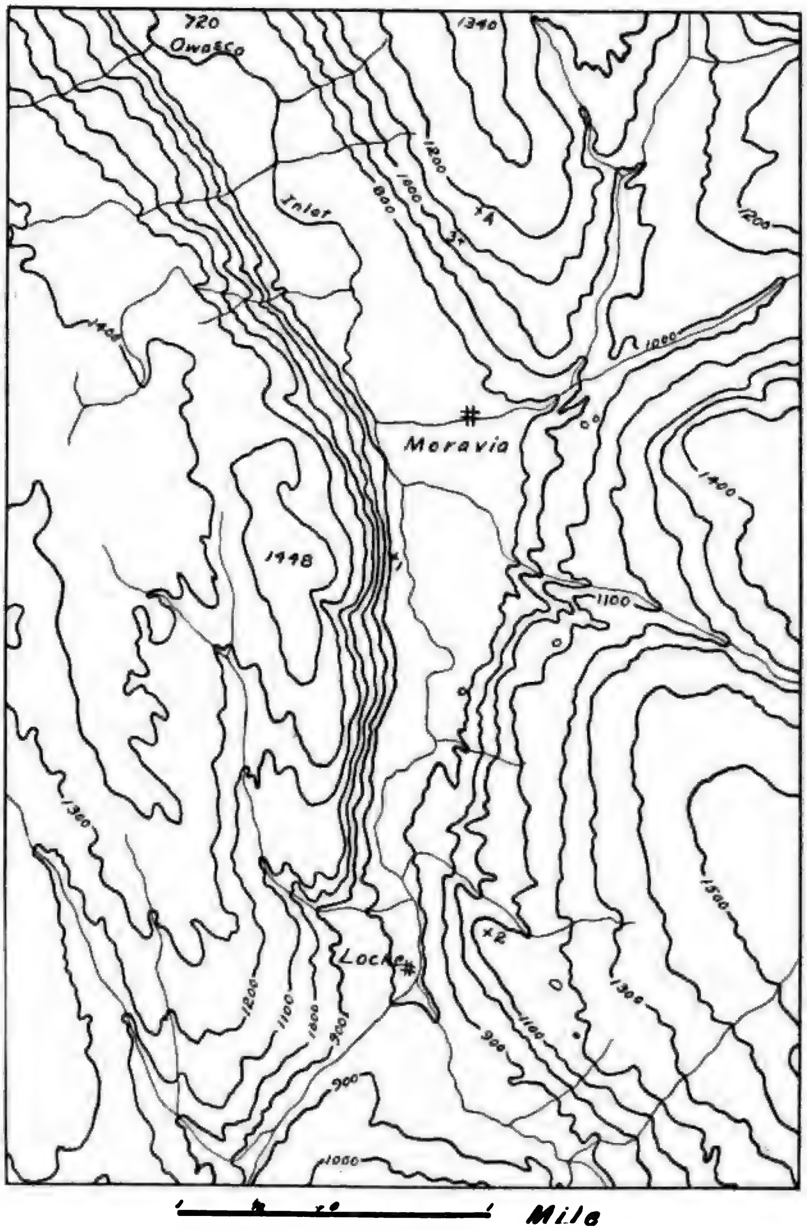


FIG. 1.—Part of Moravia Quadrangle, New York. Contour interval, 100 feet.

overlain by about two feet of drift and rubble, but this horizon very likely consisted formerly of ground moraine which was removed in the process of quarrying.

Fig. 3 is of a fold at station 3, directly north of Moravia. This photograph was taken a few days after an unusually heavy storm which caused many slight streams to leave their former courses, thus exposing fresh sections in the tile. The area shown is on the north side of such a recent cut. The axis of the fold inclines 36°, the section being approximately east-west. The fold is turned up the slope or against gravity; it consists of thin bedded shale and sandy layers amounting to about 18 inches. This is overlain by three to four feet of ground moraine, very compact, and is underlain by a hard layer of sandstone over which the stream is flowing.

HOW THESE FOLDS WERE PRODUCED

As to the causes that may have produced these folds shown in Figs. 2 and 3, which have been selected from a series of photographs of which these are typical: Does the frost theory explain this work? The probable type of a fold caused by freezing is more symmetrical, and, as shown by Sardeson, has in its upper horizon a weathered zone in which the rock has more thoroughly disintegrated, the section blending into less residual material. Fig. 3, however, is obviously below the normal frost line for this climate; while Fig. 2 doubtless shows an area that is subject to frost, as the upper part of the apex of the fold in Fig. 2 very likely has been slightly altered through the influence of frost work. In any event, however, frost folds would be more symmetrical than these. Consequently the frost theory does not seem to apply.

Little need be said concerning the theory of creep, since Fig. 3 is obviously a fold tilted against gravity, while Fig. 2 is a fold along the contour of the slope. It does not seem probable in any event that a fold due to creep would ever be overturned as Fig. 2 is.

Elsewhere in the Moravia Quadrangle folds possibly due to buckling induced by the removal of overlying strata have been observed, but these cases are always symmetrical in relation to the axis of the fold, and apparently show the effects of rather speedy giving away to certain stresses. The agent probably involved in the

removal of the overlying formations is ice, but on this heading too little field work has been done to warrant any definite conclusions. As to the folds in question, it is obvious that they are not due to buckling.

Mr. Campbell establishes the competency of joint expansion due to weathering to produce folds in certain strata. His figures and

FIG. 2.—Subjacent strata folded by glacier ice. Area shown is northeast of Locke, N. Y.

explanation impress the symmetry of such folds. For this reason the theory of weathering cannot apply to our cases.

There are several reasons that point to glacial ice as the agent involved in the present folding. In Fig. 2 the fold is overturned in the direction of ice-motion. This fold lies slightly off the line of the valley segment north of Moravia. Striae to the north and east of the fold, within a radius of one and one-half miles, give an average direction of S. 31° E.,[1] the extremes being S. 18°, and 48° E. Owing

[1] Only magnetic readings are given in this paper.

to the fact that but one section of this fold is exposed there is a possibility of some error in stating exactly the direction of the fold, but from careful study on the ground it seemed plausible that the plain shown in the view is parallel to the direction of ice-motion. If this fold were due to deep-seated stresses, the underlying formations would have suffered disturbance obviously, and since the fold is an over-

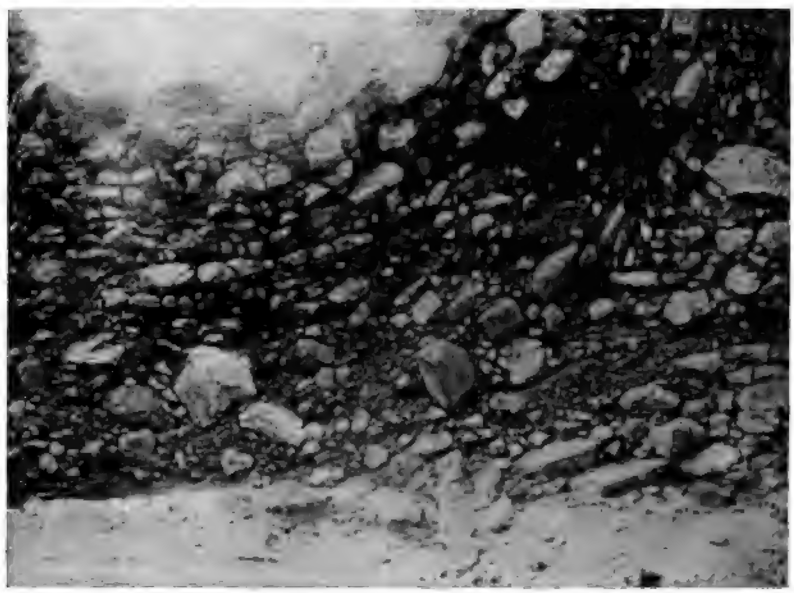


FIG. 3.—Subjacent strata folded by glacier ice. Area shown is north of Moravia, N. Y.

turned anticline it seems impossible that any cause of this nature could have become operative without deforming the sandstone beneath.

It is seen that Fig. 3 likewise shows the influence of ice-movements, but not the same type of ice-motion involved in the former case. The topographic map shows a considerable width of valley north of Moravia, a valley which flares northward opening on a fairly level plain within twelve miles. This position favored the expansion toward Moravia of a lobe of ice which had both linear and outward motions. The lateral flow of this tongue obviously produced the fold in question. Some six or seven other instances of similar folds were

noted along the slope within a mile and a half north of Moravia. Some of these were less distorted than the one shown in Fig. 3, one being fairly symmetrical, and possibly to be explained by buckling, since it is several feet below the reach of frost work. But in each case where the axis of the fold was inclined the inclination was up the slope.

It is felt, therefore, that we are dealing with the work of ice in deforming subjacent strata; we have selected cases to illustrate the work of this ice along two lines, one connected probably with the general movement of the ice sheet, or at least the linear movement of a strong valley lobe, the other connected with the outward spreading of a valley lobe.

GLACIAL EROSION

In reference to the altitudes of the localities where folding has been noted: The disturbed strata of station 2 lie approximately 1,140 feet above sea-level. The area of disturbed strata north of Moravia lies within 1,080 and 1,160 feet altitude. Very diligent search at lower and higher ranges than these has not revealed any similar phenomena, but has, however, given much information on the subject of ice-erosion.

Fig. 4 is a photograph of a freshly uncovered rock surface about a mile and a half southwest of Moravia near the foot of the steep valley wall. The well-rounded angles, showing the polishing work of the ice as block after block of the thin bedded sandstone material has been removed, the general smoothing of the whole surface, the irregular gouges and the striae attest the vigor of ice-work here. Several similar areas were likewise noted; the one shown, however, is typical and different from the others only in revealing a larger surface. Here the average direction of the striae is S. 13° E., a direction that shows the control exercised by the valley. This surface has an altitude of about 790 feet, standing but slightly more than 50 feet above the inlet stream near the base of the valley wall. The slope of the polished surface has the general grade of the valley wall immediately above and below. While this surface is very illustrative of the corrasive work of ice, it is felt nevertheless that the processes of ice degradation which it represents are of the same type as have probably been effective in giving the valley cross-section its U-outline.

Directly west of Moravia at approximately the 900-foot contour is another area showing numerous striations which have an average direction of S. 37° E. The surface at this place is slightly steeper than that just noted. It also stands higher above the flood plain below.

East of Moravia near the forks in the highway leading up the hill is another area of very active ice-polishing. Its altitude is 830 to

FIG. 4.—Glaciated surface southwest of Moravia, N. Y.

860 feet. We note here, however, two sets of striae; the stronger measures S. 56°–63° E. This set probably represents the general movement of the ice-sheet, modified perhaps slightly by local topography. The direction of the weaker set is S. 19°–25° E. It should be noted that this surface stands at an angle in the Owasco Inlet valley. The north leg of this angle has approximately the direction of N. 32° W., and the south leg, S. 8° W. Leading into the major valley from the east a tributary valley enters at this point. The striated surface, however, is some 100 feet below the rock bottom of this tributary valley which in accordance with the recent literature would be called a "hanging valley." It is possible, therefore, that

this relation of valleys here has tended to mollify the general effectiveness of ice-corrasion.

On the uplands striated surfaces again appear. These surfaces range from 1,200 to 1,400 feet in altitude, and even above this they are to be found on the salients opposed to the direction of ice-motion. Averages of several scores of readings made in different localities ranging between the 1,200- and 1,400-foot contours give S. 46°–48° E. The averages of striae on surfaces still higher give S. 53°–61° E. These areas fall within a reach of three miles of the major

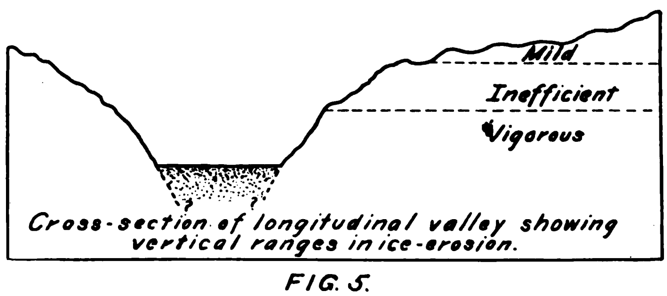


FIG. 5.—Cross-section of longitudinal valley showing vertical ranges in ice-erosion.

valley; in the main they are found in the general flat country constituting plateau divides.

Between the two zones of ice-erosion already mentioned, that is the areas near the bottom of the major valley and the areas on the uplands, lies another zone of least effective ice-work. This is the horizon of the folded subjacent strata; in the Owasco valley area it is approximately between the 1000- and 1200-foot contours.

Fig. 5 summarizes these observations. The cross-section is normal to the axis of the longitudinal valley, not taking note of the deflections of this axis. The matter of altitude in relation to sea-level is likewise neglected, as great discordance may exist between present-day and Wisconsin ice-epoch altitudes. So little is known definitely about the relation that existed, during Pleistocene time, between the land mass of northeastern North America and sea-level, and furthermore, the connection between ice-erosion and a base level from which altitude is measured, may probably be so slight, that this relation, as a factor, may safely be neglected. The topographic

aspect of the region of our cross section, however, is very important. In the uplands, or divide plateau areas, glaciated surfaces are found wherever the rock is not drift-covered. These striated surfaces attest considerable planing or abrasive work by the ice-sheet. As these flat elevated areas decline to the valleys we find a range of very subdued ice-work, the zone of disturbed subjacent strata, and of residual rock decay *in situ*. But proceeding down the valley slopes the evidence of ice-corrasion gradually increases. The strongest evidence so far noted in the field is found within a short distance vertically of the flood plain. We have then (Fig. 5) three ranges showing variation in the effectiveness of ice-erosion: (1) the range of mild erosion; (2) of inefficient erosion; and (3) of vigorous erosion.

Reviews

A Note on the Geology of Gough Island. By J. H. HARVEY PIRIE. *Notes on the Petrology of Gough Island.* By R. CAMPBELL. (Proceedings of the Royal Physical Society of Edinburgh, session 1905–06; Vol. XVI, No. 6, pp. 258–66. Edinburgh, 1907.)

This island is a peak in lat. 40° 20′ S., long. 9° 56′ W. composed of horizontal basalts, trachytes, trachy-dolerites, and tuffs. The island is encircled by wave-cut cliffs over which the streams cascade into the sea.

C. W. W.

Montana Coal and Lignite Deposits. By JESSE PERRY ROWE. (Bulletin No. 37, University of Montana, Geological Series No. 2. Pp. 82, 26 plates. Missoula, Mont., 1906.)

Coal occurs in the Jurassic, Cretaceous, and Tertiary. The workable coal is limited to the Cretaceous and is both lignitic and bituminous. Mining is carried on to supply the local demand only, most of the coal being used in connection with smelting and other industries. In 1904 the state produced about 1,500,000 tons of coal and lignite, valued at about $2,450,000. The annual output of coke is about 57,000 tons.

C. W. W.

Geological Survey of Michigan, Annual Report, 1904. Including a geological map of Michigan. Pp. 182, 16 plates. Lansing, Mich., 1905.

Contents: "Failure of Wells along the Lower Huron River, Michigan, in 1904," by Myron L. Fuller; "A Geological Reconnaissance along the North Shores of Lake Huron and Michigan," by Israel C. Russell; "Sixth Annual Report of the State Geologist," by Alfred C. Lane.

C. W. W.

Iowa Geological Survey (Vol. XV, Annual Report, 1904). By FRANK A. WILDER, State Geologist, Des Moines, 1905.

Contains: "Statistics of Mineral Production for 1904;" "Cement and Cement Materials of Iowa," by Edwin C. Eckel and H. F. Bain; and reports on the geology of seven counties. C. W. W.

Maryland Geological Survey, Vol. V, 1905. By WILLIAM BULLOCH CLARK, State Geologist. Baltimore, 1905.

Contains reports on magnetic observations, county boundaries, highways, coals, coal formations and their correlation, coal mines, and on the chemical and heat-producing properties of Maryland coals.

The Configuration of the Rock Floor of Greater New York. By WILLIAM HERBERT HOBBS. (Bulletin No. 270, U. S. Geological Survey. Pp. 96, 5 plates. Washington, D. C., 1905.)

This paper is a record of existing data on the form of the rock surface of New York. The waterways about Manhattan Island are described as steep rock canyons 200 to 300 feet deep, partially filled with drift. The main lineament of the rock topography is assigned to faulting.

C. W. W.

Tertiary and Quarternary Pectens of California. By RALPH ARNOLD. (U. S. Geological Survey, Professional Paper No. 47. Pp. 264, 53 plates. Washington, D. C., 1906.)

This paper is a monograph of the California fossil Pectens, and contains also descriptions of Pectens from other localities on the Pacific Coast, with a summary of California Marine Tertiary paleontology.

C. W. W.

Cretaceous Section in the Moose Mountains District, Southern Alberta. By D. B. DOWLING. (Bulletin of the Geological Society of America, Vol. XVII, pp. 295–302. 1906.)

The formations described are: the Kootanie, Dakota, Colorado, Eagle, Claggett, Judith River (Belly River), Bearpaw (Pierre), and Edmonton (Saint Mary River). A fuller report will be made by Mr. D. D. Cairnes.

C. W. W.

Status of the Mesozoic Floras of the United States. By LESTER F. WARD, with the collaboration of WILLIAM M. FONTAINE, ARTHUR BIBBINS, and G. R. WIELAND. Second Paper. (U. S. Geological Survey, Monographs, Vol. XLVIII. Part 1, text, 616 pp.; Part II, 119 plates. Washington, D. C., 1905.)

This report contains descriptions of the Triassic flora of Arizona; the Jurassic floras of Oregon, Alaska, California, Montana and Wyoming;

and the Cretaceous floras of the Potomac and Shastan Series, and of the Kootanie (Montana), Lakota (Black Hills), and Trinity (Texas) formations. C. W. W.

Geological Survey of Ohio. By EDWARD ORTON, JR., State Geologist, Bulletin Nos. 4 and 5, Fourth Series. Columbus, Ohio, 1906.

Contains: "The Limestone Resources and the Lime Industry in Ohio," by E. Orton, Jr., and S. V. Peppel, and "The Manufacture of Artificial Sandstone or Sandlime Brick," By S. V. Peppel.

The Differentiation of a Secondary Magma through Gravitative Adjustment. By REGINALD A. DALY. Separate from the *Festschrift zum siebzigsten Geburtstage von Harry Rosenbusch, gewidm. v. seien Schülern.* Stuttgart: E. Schweizerbartsche Verlagsbuchhandlung, 1906. Pp. 201–32.

This paper is similar to an earlier one[1] by the same author, but contains a fuller description and new chemical analyses of the Moyie Sell in the Purcell Range of British Columbia. This great sill, 840 meters thick, is composed of hornblende gabbro grading upward into granitite which lies along the upper surface with a thickness of about 45 meters. The latter rock is thought to have been derived by assimilation of the country rock (quartzite) in the gabbro, and subsequent segregation of the lighter granitic material at the top of the sill. C. W. W.

The Champlain Deposits of Northern Vermont. By C. H. HITCHCOCK. (From the *Fifth Report on the Geology of Vermont*, by PROFESSOR G. H. PERKINS.) Pp. 24. Montpelier, Vt., 1906.

According to the author it is easier to invoke the glacial dam to account for the various Pleistocene beaches, benches, wave-cut notches, and sea cliffs than to appeal to changes of level. Glacial Lake Champlain may have been from 200 to 300 feet higher than the marine limit. Glacial Lake Memphremagog discharged through the Elligo pond col into the Lamoille Valley and was tributary to Glacial Lake Champlain.

C. W. W.

New Forms of Concretions. By HENRY WINDSOR NICHOLS. Publication 111, Geological Series, Field Columbian Museum, Vol. III, No. 3. Pp. 25–54; plates IX–XXVII. Chicago, 1906.

[1] "The Secondary Origin of Certain Granites," *American Journal of Science*, Vol. XX, pp. 185–216. 1905.

Very complete descriptions are given of new types of concretions from many localities. Students of concretions will find in this paper some original and helpful methods of research. There are also observations which may bear on the principles of ore-deposition. Some concretions from the deep-sea are found to have the composition of dolomitic limestone, indicating that dolomite may be formed directly from ocean water. The paper closes with a useful discussion of the determination of the specific gravity and the modulus of rotundity of concretions.

C. W. W.

The Geology oj the Granby Area. By E. R. BUCKLEY AND H. A. BUEHLER. Missouri Bureau of Geology and Mines, Vol. IV, Second Series. Jefferson City, Mo., 1906.

The authors conclude that faults have had nothing to do with the origin of the lead and zinc ores of this district. The so-called fault breccias are mostly basal conglomerates of the Pennsylvanian System. Nor were the ores derived from the underlying Cambro-Ordovician magnesian limestone by an artesian circulation, as held by Van Hise, Bain, and others, because the water from deep wells in the latter rock contains no zinc or lead. The ores were probably derived from overlying Pennsylvanian shales and limestones, and concentrated wholly by downward-moving waters.

The report contains an extended discussion of the chemistry of the ores and a few pages on methods of mining, concentrating, and melting.

C. W. W.

Geological Survey ej New Jersey. Annual Report of the State Geologist for the year 1905. By HENRY B. KÜMMEL, State Geologist. Trenton, N. J., 1906.

The report contains: "Changes along the New Jersey Coast," by Lewis M. Haupt; "A Brief Sketch of Fossil Plants," and "The Flora of the Cliffwood Clays," by Edward W. Berry; "The Chemical Composition of the White Crystalline Limestones of Sussex and Warren Counties," by Henry B. Kümmel, with analyses by R. B. Gage; "Lake Passaic Considered as a Storage Reservoir," by C. C. Vermeule; "A Report on the Peat Deposits of Northern New Jersey," by W. E. McCourt and C. W. Parmelee; "The Mining Industry," by Henry B. Kümmel.

THE

JOURNAL OF GEOLOGY

NOVEMBER-DECEMBER, 1907

THE WITWATERSRAND GOLD REGION, TRANSVAAL, SOUTH AFRICA, AS SEEN IN RECENT MINING DEVELOPMENTS[1]

R. A. F. PENROSE, JR.

Location.—The name Transvaal is applied to a stretch of country lying north of the Vaal River and south of the Limpopo River. It comprises 106,642 square miles and is bounded on the south by the Orange River Colony and Natal, on the west by Cape Colony and Bechuanaland, on the north by Rhodesia, and on the east by Portuguese East Africa and Swazieland. From the lowlands along the Limpopo River the region rises gradually to the south and southeast, and in the southern part is an elevated plateau rising between five thousand and six thousand feet above the sea. This plateau is an open country, heavily covered with grass, with but few trees, and resembling in many respects some of our western states. It is capped by a low range of hills running about east and west and known as the Witwatersrand, or "white-water-ridge." This range is the divide between the waters of the Vaal and the Limpopo rivers, and in fact is the continental divide in this part of Africa, as the Vaal River runs into the Orange River and thence to the Atlantic, while the Limpopo River empties into the Indian Ocean.

[1] During a recent trip to South Africa the writer spent some time studying the occurrence of gold in the Witwatersrand region of the Transvaal. So much has already been written by others on this subject that it is not intended here to enter into a detailed description of the region, but only to discuss some of the more general features as seen in the light of recent developments.

On the southern slope of this divide, where it drops off toward the Vaal River, are the celebrated gold mines of the Witwatersrand, a name locally abbreviated to the Rand. The mines occur at frequent intervals for some fifty miles in a general east and west direction along the Rand, with the town of Johannesburg about midway along this line, while the ore-bearing formation has been traced even beyond these limits.

History.—Rumors of the gold of Africa have existed from the most remote times, some of them vague and indefinite, but some more specific, and there seems to be reason to believe that many sources of very ancient wealth were located there. Later on the Phoenicians are known to have bartered extensively in it, and the Arabs in the Middle Ages knew of it, and are supposed to have derived great wealth from it. The Portuguese explorers in the early part of the sixteenth century heard of it and made several more or less serious attempts to work it. It is probable, however, that most of the deposits known to them and to the earlier people were in the vast region extending from north of the Witwatersrand up to tropical Africa, though even in the Witwatersrand signs of old gold workings are said to have been found.

It was not, however, until the latter half of the nineteenth century that modern gold mining in the Transvaal was actively begun. In 1845 Von Buch, and some twenty years later Carl Mauch, reported gold in South Africa. It is said to have been discovered on what is now known as the Witwatersrand, or Rand, as early as 1854, but the Boers opposed its exploitation. In 1870 gold was discovered in the Murchison Range in northeastern Transvaal, and in 1873 mining was begun near Lydenburg, somewhat farther south. In 1875 gold was discovered in the DeKaap gold fields in eastern Transvaal, but active work did not begin until some years later. In 1885 the Sheba mine was discovered in the same region and the town of Barberton soon became a noted mining-center. A few years later, however, it was almost abandoned by the rush to the Witwatersrand. Placer gold mining had been carried on there in a small way for some time, but the first "reef" mining was begun in 1884 and 1885, and in 1886 Johannesburg was founded. From the start the industry grew until now the Witwatersrand is the greatest gold-mining district in the world.

Many other gold districts have been discovered in the Transvaal, Rhodesia, Natal, the Portuguese possessions, and other parts of South Africa, but the Witwatersrand still easily maintains its pre-eminence.

Geological relations of the gold deposits.—The gold of the Witwatersrand occurs as an impregnation of certain conglomerate beds which are members of a series of quartzites, conglomerates and slates known as the Witwatersrand system. These strata lie unconformably on

FIG. 1.—Underground photograph at the Nourse-Deep Mine, Witwatersrand District, Transvaal, showing dike and faulting in the gold-bearing conglomerate. The speckled rock in the picture indicates the conglomerate.

older rocks known as the Swazieland series and classed by the local geologists as Archaean.[1] The Witwatersrand system has as yet afforded no fossils, so that its exact age is not known, but judging from fossils found in overlying formations, the Witwatersrand rocks are supposed to belong at least as low as the lower part of the Paleozoic and possibly lower in the geological column.

The Witwatersrand system is divided into an upper and a lower series, though there is no unconformity between them, the only dif-

[1] Hatch and Corstorphine, *The Geology of South Africa*, 1895.

ference being that the lower series is composed largely of slates, with quartzites and rarely some thin conglomerates, while the upper series is composed largely of quartzites, with prominent conglomerates and some little slate. Sheets of diabase are interbedded with both the upper and lower series, and diabase dikes cutting the strata t ansversely are of frequent occurrence (Fig. 1). The whole Witwatersrand system is much faulted and broken, especially at the east and west ends of the district, making estimates of its thickness in some p'aces often very uncertain. It is known to vary considerably in thickness, however, in different parts of the region, being much thicker in the estern part of the Witwatersrand than in the eastern part. In the central part of the district the upper and lower series of the system are each about ten thousand feet or possibly somewhat more in thickness, giving an aggregate thickness for the whole system of approximately twenty thousand feet.[1] To the east they are thinner and to the west thicker.

'he Upper Witwatersrand series has been divided by the South African geologists into several different formations, each one consisting largely of quartzite but marked by more or less prominent conglomerate beds. These conglomerates are locally known among the miners as "reefs," and the term has been retained in some of the local geological nomenclature. The divisions of the Upper Witwatersrand made by Hatch and Corstorphine[2] are, in a descending order, the Elsburg series, the Kimberley series, the Bird Reef series, the Livingstone Reef series, and the Main Reef series. The gold of the Witwatersrand mines occurs mostly in the Main Reef series, lying as it does at the base of the Upper Witwatersrand and just above the Lower Witwatersrand series. Small quantities of gold have been found elsewhere in the Upper Witwatersrand series, bu: rarely in paying quantities, though in some places extensive work has been done in search of it. Small quantities of gold have also been found in the Transvaal in other conglomerates than those of the Witwatersrand system, but have not become of great importance. This is

[1] Hatch and Corstorphine, *op. cit.*, pp. 108, 125.

[2] *The Geology of South Africa*, p. 122. Some doubt is expressed by these writers as to whether the Elsburg series belongs to the Upper Witwatersrand or to the overlying Ventersdorp system. This matter, however, is not of great importance in the present discussion, as almost all the profitable mines on the Witwatersrand are in the Main Reef series.

especially true of the conglomerates of the Black Reef series of the Potchefstroom system, which belongs considerably higher up in the geological column than the Witwatersrand system. A number of attempts have been made to work the Black Reef gold, but so far the success has been small, though in a few instances a certain amount of profit is said, at least temporarily, to have been obtained.

Besides its occurrence in conglomerates, gold is found under various other conditions in various places in the Transvaal, but these

Fig. 2.—Photograph of surface workings in the Crown Reef Mine, Witwatersrand District, Transvaal. The steeply dipping strata underneath the hoisting works on the right-hand side of the picture are the outcrop of the gold-bearing conglomerate.

occurrences are not within the scope of this article. Among them, however, may incidentally be mentioned the auriferous quartz veins in rocks of the Swazieland series in the Barberton region and near Pietersburg; the quartz veins in the rocks of the Dolomite series near Lydenburg and at Malmani; the quartz veins in rocks of the Pretoria series west of Pretoria and west of Krugersdorp as well as elsewhere; the placer workings in many places. The importance of all these occurrences, however, has proved small compared with the gold in the conglomerates of the Main Reef series of the Witwatersrand, the

latter being what has made the Transvaal pre-eminent as a gold producer.

Mode of occurrence of the gold deposits.—The Main Reef series, which, as just stated, carries most of the gold of the Witwatersrand district, contains several gold-bearing conglomerates separated by quartzites of a light-gray or greenish-gray color, dense, brittle, and of either a vitreous or hard sandy structure. More rarely slaty strata occur. On the extreme eastern part of the Rand the conglomerates

FIG. 3.—Underground photograph in the Ferreira-Deep Mine, Witwatersrand District, Transvaal, showing the gold-bearing conglomerate running diagonally across the picture. The speckled rock indicates the conglomerate.

often come close together and are sometimes all within a distance of a few feet of each other. To the west they are scattered over a greater thickness of strata, sometimes one hundred feet or more, measured vertically to the dip. This widening is due chiefly to the widening of the interbedded quartzites, though the conglomerates also increase to some extent. The conglomerate beds vary in number in different places, but certain of them have become especially prominent as gold-producers, the chief ones being known locally as the Main Reef and the South Reef, while the Main Reef Leader and the South Reef

Leader, are usually smaller but often rich beds. Other less important conglomerates are the North Reef, the Middle Reef, etc.

The Main Reef, from which the Main Reef series has received its name, is generally the largest, and ranges from a few feet to probably fifteen feet or more in thickness, though usually not of high grade. It outcrops along a general east and west course throughout the district, and dips in a southerly direction at angles which are often steep near the surface, frequently 80° or more (Fig. 2), and shows a tendency

FIG. 4.—Underground photograph in the Jumpers-Deep Mine, Witwatersrand District, Transvaal, showing the gold-bearing conglomerate running diagonally across the picture. The speckled rock indicates the conglomerate.

to flatten in depth, a dip of from 40° down to 20° or less being common at no great depth (Figs. 3, 4, and 5). The South Reef lies to the south of the Main Reef and is separated from it by intervening strata of a thickness of from a few feet to ninety feet or more. It is usually somewhat smaller than the Main Reef but is usually richer. It is parallel to, and shows the same variations in dip as the latter. The Main Reef Leader is a conglomerate bed almost immediately overlying the Main Reef and separated from it by only a few inches to a

few feet of intervening strata; in fact the two sometimes seem to come together. It varies from a few inches to several feet in thickness, but is usually thin, though often rich in gold. Sometimes, especially on the eastern part of the Witwatersrand district, a very persistent slaty parting occurs between the Main Reef and the Main Reef Leader, and is locally known as "the interbedded dike." Another small conglomerate, the South Reef Leader, lies immediately under the South Reef, and is also often rich in gold. The Middle Reef is a very low-grade body of conglomerate ore lying between the Main and South Reefs; and the North Reef is also a low-grade bed lying below the Main Reef.[1]

Sometimes still other conglomerate beds than those mentioned occur, while at other times some of the beds mentioned are wanting. In fact the conglomerates are more or less lenticular strata, widening and thinning at intervals, and sometimes disappearing altogether. In some places two or more beds may blend into one, or any one bed may be split up into two or more beds separated by quartzite; so that in different localities, a different number of conglomerates may be found, and those that have been described above are simply those that are usually the most continuously represented. Sometimes what seem to be the same conglomerates change their positions slightly in the associated strata and are a little higher or a little lower in one place than in another, while sometimes the formation is very much faulted, so that it is often difficult to correlate certain beds in different places. On the whole, however, the conglomerates, as compared with conglomerates elsewhere, may be said to be remarkably continuous over long distances, and this feature of the ore bodies has been one of the chief factors in the wonderful development of the mining operations of the region.

Though the conglomerates mentioned all carry gold, yet the quantity varies considerably in the different beds and even in different places in the same bed. The main Reef, though large, is generally of rather low grade, but it is worked in many places at a good profit. The South Reef and the Leaders are usually of higher

[1] Some of the reefs mentioned here are sometimes known by different names in different parts of the district, but the names given above are those most commonly used.

grade, one or both of the Leaders often being of much better grade than either the Main or South Reef. Though the conglomerates carry most of the gold, in fact all the gold that is mined in the Main Reef series, yet small quantities have been found in some of the quartzites.

The gold-bearing rocks of the Witwatersrand district, dipping, as they do, in a southerly direction, occupy the northerly side of a synclinal fold and come to the surface again in the Heidelberg dis-

FIG. 5.—Underground photograph at the Durban-Roudepoort-Deep Mine, Witwatersrand District, Transvaal, showing old workings from which the ore has been removed.

trict, some thirty miles southeast of Johannesburg, and on the Vaal River still farther south. More or less gold mining has been carried on in these more southerly districts, but much less extensively than in the Witwatersrand district. On the Witwatersrand the gold formation can be traced along its strike for over sixty miles, and at either end it disappears beneath younger strata. The claim is made, however, that it has been traced with the assistance of borings for over one hundred and sixty miles, and that there is more or less evidence of its extent, though interrupted by faults and covered by more recent strata, for over three hundred miles. So far, however,

none of the outlying districts have become very great producers, while even in the Witwatersrand district it is in only certain parts that highly remunerative results have been obtained. The conglomerates seem to be richest in the central part of the district, and to decrease in value on the east and the west ends. A large percentage of the gold comes from the mines along some twenty-five or thirty miles of the central part of the district, but for a distance of some fifty miles, east and west, there are scattered considerably over a hundred mines. Such a record, both for the number of mines in a given distance on one deposit, and for the percentage of profitable ones among this number, is probably unprecedented anywhere else.

Nature of the ore.—The ores of the Witwatersrand district consist, as already stated, of conglomerates impregnated with gold, and are frequently known by the Boer term "banket." The conglomerates, in their general character, do not differ from many conglomerates in other parts of the world except in their content of gold. The pebbles are well rounded and vary from a small fraction of an inch to several inches in diameter, most of them probably ranging from about a quarter of an inch to about an inch and a half or two inches. They are imbedded in a sandy matrix cemented by secondary silica, which knits them into a solid mass, and often forms small lenses, or irregular bodies of quartz, in the conglomerate. The rock thus cemented is massive and compact, and when broken the fracture often passes through the pebbles as readily as around them. Iron pyrites and marcasite are abundant, and a greenish chloritic or sericitic material often occurs encircling the pebbles and impregnating the matrix. Flakes of muscovite are not uncommon, and under the microscope other minerals, including rutile, zircon, magnetite, corundum, tourmaline, etc., are to be seen.[1]

The pebbles are mostly of a transparent, white, or smoky character, while more rarely some have the appearance of chalcedony, jasper, or chert. Sometimes fragments of quartzite and slate occur in the conglomerate, but they are few as compared with the quartz pebbles. In some places it is found that the coarser the pebbles, the richer the conglomerate in gold, but this does not always hold good, and sometimes the finer conglomerates are the richer. All the Witwatersrand ores are more or less impregnated with iron sulphides, pyrite

[1] Hatch and Corstorphine, *op. cit.*, p. 136.

and marcasite, which vary somewhat in amount in different places. Though the sulphides are usually abundant where the ore is rich in gold, yet they are also often abundant where the ore carries very little gold, so that the quantity of them is not necessarily an indication of the richness of the ore. They are sometimes very finely disseminated in minute particles, at other times in a coarser condition, generally crystalline, and sometimes in concretionary or radiating nodules. They are generally oxidized for a few hundred feet from the surface, giving the ore a brown, rusty appearance, while at a greater depth the ore assumes a gray or greenish-gray color.

The gold is finely disseminated in the ore and is rarely noticeable to the naked eye, though it can sometimes be seen in thin flakes incrusting the pebbles, or in small particles in the siliceous matrix. The gold is not uniformly distributed through the reefs. There are rich places and poor places, but in spite of this, it may be said that the gold is much less irregular over long distances than in most gold deposits, and in no other part of the world can so many mines be seen on the same ore body.

Most of the ores mined in the Witwatersrand district are of low grade, though bodies of higher-grade ore occur, and more rarely small amounts of very rich ore are found. The value usually varies from a grade too low to work profitably up to about $25 per ton and sometimes to very much more. Under the ordinary conditions existing in the district, ore of $6 per ton is about as low-grade material as it pays to work, and most of the ore at present being treated ranges from about that value up to $12 or $15 per ton. The average value of the ore mined in the Witwatersrand district in the year ending June 30, 1905, was from 36.888 to 37.123 shillings,[1] or a little less than $9 per ton.

In the early days only the higher-grade ores were worked, but with the increased facilities for mining and milling, the cost was diminished, and the tendency is, therefore, to save the lower-grade ores which were once thrown away, and to mix them with the higher-grade ores, thus bringing down the average value of the ore treated, but adding to the aggregate amount of gold produced.

The mines vary in depth from a few feet to over 4,000 feet, quite a

[1] "Transvaal Mines Department," *Annual Report of the Government Engineer for the Year Ending June 30, 1905*, p. 8.

number ranging from 1,500 to 2,500 feet, and a few deeper. Those located on the outcrop of the ore are known as "outcrop" mines; the adjoining ones to the south, which are not on the outcrop, but which require a shaft to be sunk to reach the ore on its dip, are known as the "first row of deeps," those next farther south are known as the "second row of deeps," etc. The general term "deep" is thus applied to any of the mines not on the outcrop, and the first, second, third, and even fourth rows of deeps are common terms. The word

FIG. 6.—Photograph of surface at the Robinson and the Robinson-Deep Mines, Witwatersrand District, Transvaal, showing tailings, dumps, and general surface conditions.

"deep" does not refer in any way to the depth of the mine, but only to the fact that a shaft has to be sunk to reach the ore.

It is not within the scope of this article to discuss the metallurgical treatment of the Witwatersrand ores. It may be said, however, that nowhere else in the world have the mining and treatment of gold ores been carried on with greater efficiency and skill than by the able engineers and metallurgists who have conducted the operations on the Rand; and nowhere has the gold-mining industry been conducted on such a large scale. The ores are treated in large stamp

mills located at or near the mines (Fig. 6), and it is a striking sight to look out from some elevated place and see the long row of immense milling plants following an east and west line as far as the eye can reach along the strike of the ore formation. The ore is partly free milling. About 55 to 65 per cent. of the gold is saved on amalgamating plates, and a large part of the rest is obtained by cyaniding the tailings. Sometimes additional processes to make a more complete extraction are practiced. A well-equipped and well-managed mill, with the present methods, should make a total extraction of probably from 88 to over 90 per cent. of the gold in the ore.

The Witwatersrand district is essentially a region of large quantities of low-grade, yet workable, ore, and there are but few places in the world where gold mining can be carried on so cheaply as there. The ore bodies extend over long distances, and their contents of gold is much less erratic than in most gold mines elsewhere; coal, which is the only available fuel, is found in large quantities in close proximity to the mines, in geological formations overlying the gold-bearing rocks; Kaffir and Chinese labor is cheap, though at present somewhat scarce; the climate is healthy; the mines as a rule are not troubled with any excessive amount of water; the temperature does not increase at a very rapid rate with depth; and the rock is of such a kind that the expense for timber to hold up the underground workings is not great (Fig. 5). Under all these favorable conditions mining can be carried on to very considerable depths so long as the ore holds out, and it is probable that active mining operations will be continued in this region for many years.

The production of the Rand mines from 1884 to June 30, 1906, was over 134,000,000 pounds sterling, or somewhere about $650,000,000, which means practically almost the total production of the Witwatersrand district from the start, as not much gold was obtained there before 1884. The production for 1906, according to the estimates of the Transvaal Chamber of Mines, was 24,579,987 pounds sterling.[1]

It is not intended in the present article to discuss the origin of the Witwatersrand gold ores in detail, but perhaps a few words about the generally accepted ideas on this subject may be well.

[1] These figures for 1906 were kindly furnished to the writer by Mr. W. R. Ingalls, editor of the *Engineering and Mining Journal*, of New York.

The origin of the conglomerates themselves, without reference to the gold in them, was doubtless similar to that of many other conglomerates elsewhere, that is, they were formed by the accumulation of gravel and sand under water near shore. It is probable that they are of marine origin and were laid down along the shore line of some more or less open sea. Later on they were covered by other strata, then elevated into a land area, folded and distorted by the dynamic action to which the region has been subjected, then more or less eroded by atmospheric influences, and eventually left as they are now found.

As to the source of the gold in the conglomerates, there has been much more dispute than as to how the latter were formed. Two different theories, among the several that have been advanced on this subject, seem to have received most support. One of them supposes that the gold is all detrital, that it was deposited mechanically with the pebbles of the conglomerates at the same time as these beds were formed, and that it came from the same rocks as the pebbles, or at least from adjacent rocks. In other words, this theory supposes that the gold-bearing conglomerates are simply old placer deposits. The second theory supposes that the gold was brought into the conglomerates after the latter had been formed and probably after they had been elevated into land areas, that the conglomerates simply acted as pervious strata through which gold-bearing solutions found a ready passage, and in which the gold was deposited in much the same way as it is supposed to have been deposited in the fissures containing it in most gold districts.

George F. Becker[1] supports the first theory and believes that the gold was deposited mechanically with the pebbles of the conglomerates and that it came from the erosion of the same land area, though it may have been somewhat changed in position and character by subsequent chemical action. He thinks the conglomerates are of marine origin, and that they are in fact simply marine placers, solidified by the later deposition of secondary silica.

Messrs. Hatch and Corstorphine,[2] on the contrary, believe in the second theory, that is, that the gold was deposited from solutions

[1] "The Witwatersrand Banket, with Notes on Other Gold-Bearing Pudding Stones," *United States Geological Survey, Eighteenth Annual Report, 1896–7*, Part V, "Metallic Products and Coal;" pp. 173–77.

[2] *The Geology of South Africa*, pp. 145, 146.

POTFONTEIN
VLAKFONTEIN
HOLFONTEIN
KLIPFONTEIN
MODDERFONTEIN
WELTEVREDEN
GEDULD
GROOTVLEI
SPRINGS
WITPOORT
RIETFONTEIN
DAGGAFONTEIN
SCALES.

permeating through the conglomerates after their formation, in much the same manner as gold is deposited in fissures elsewhere. They think that with the gold were also deposited the pyrite, marcasite, and other secondary minerals found in the deposits, including the secondary silica, which has bound the once open pervious conglomerates into solid compact rocks. Most of the geologists and engineers who have been directly connected with the mines in the Witwatersrand district also hold more or less similar beliefs. John Hays Hammond,[1] formerly the noted engineer of the Consolidated Goldfields of South Africa, thinks that a large part of the gold got into the conglomerates in this way, but that some of it was also deposited originally with the conglomerates.

W. H. Penning[2] and L. DeLaunay[3] have suggested that the conglomerates were formed in sea water which was heavily charged with gold and iron sulphide in solution, and that these were deposited in the conglomerates during their formation. This theory has not received much support from others familiar with the region.

[1] "The Genesis of the Witwatersrand Banket," being chap. vi of *The Witwatersrand Goldfields, Banket and Mining Practice*, 1898, by S. J. Truscott.

[2] *Jour. Soc. Arts*, London, Vol. XXXVI, 1888, p. 437.

[3] *Les mines d'or du Transvaal*, 1896.

METAMORPHISM BY COMBUSTION OF THE HYDROCARBONS IN THE OIL-BEARING SHALE OF CALIFORNIA[1]

RALPH ARNOLD AND ROBERT ANDERSON
Washington, D. C.

CONTENTS

INTRODUCTION

A unique variety of metamorphism has been at work locally in many regions of bituminous rocks in California, where a process of combustion of the hydrocarbon contents has altered the naturally white, soft shale to a rock of brilliant rose or brick-red color, and rendered it in cases hard and vesicular like scoriaceous lava. The resemblance of the products to those of volcanoes and the existence of centers like solfataras where the process of burning has been going on during the last half-century, has given rise to the statement that there were living volcanic vents in Santa Barbara County. Though the combustion is usually local in its effects, the number and wide distribution of the occurrences of burnt shale lend importance to the phenomenon. The presence of burnt shale at depths varying from 90 to 1,040 feet below the surface, as discovered in the drilling of oil wells, proves that the burning has taken place deep down within the oil-bearing formation, as well as at the surface where it has been more commonly found. And further, the discovery of fragments of it at one place at a depth of at least 10 feet below the surface in bedded deposits of Pleistocene age proves that such action has gone on not alone in recent times. The present article deals with some

[1] Published by permission of the Director, U. S. Geological Survey.

typical occurrences of shale altered in this way in the region of the oil fields of Santa Barbara County.

The Monterey shale, of middle Miocene age, is the oil-bearing formation, and the process of burning has had its chief effect upon portions of this formation. It is composed almost exclusively of soft and hard, thin-bedded, siliceous shales, which are largely of diatomaceous origin (see Fig. 1).

INSTANCES IN WHICH THE SHALE IS AT PRESENT BURNING

A number of instances have been observed in which combustion is at present or has been in recent years in progress within the Monterey shale. One example is afforded on the north side of Graciosa Ridge south of the Santa Maria Valley near the Rice Ranch oil well No. 1. When this locality was visited by the writers early in the autumn of 1906 a fire was burning underground in the shale, causing a smoke of disagreeable odor to issue from the surface and making the ground hot over an area of many square yards. Oil was oozing up at various points near by, and the ground was heated in the neighborhood of all of these seepages. The holes from which vapor issued were coated with delicate crystals of sulphur. At the point where the burning was actually going on and all about in the vicinity, for a distance of several hundred feet in some directions, the shale was altered to a bright red color, or baked almost to the hardness of compact igneous rocks, or rendered vesicular like lava.

There can be no doubt that this fire was supported by the bituminous material in the shale, and its starting was probably due to brush fires. The brush round about had been burnt, but the fire had swept over it a good many months before, as shown by the new growth on the bushes. It was said that there was a brush fire about January 1, 1906, which started the fire in the shale, and that futile attempts had been made ever since that time to put out the underground fire by dumping dirt upon it in the attempt to smother it. It seems likely, however, that this same fire has been in progress for several years. This likelihood is borne out by other accounts. It is stated that sometimes during the course of brush fires on the hills sudden darts of flame may be seen at night from a considerable distance—the result of the setting on fire of gas escaping from the rocks.

Similar phenomena were mentioned[1] by Thomas Antisell half a century ago as existing in the region near the coast east of Santa Barbara, but they were regarded by him as being of a volcanic nature. Of the foothills of the Santa Ynez Mountains a few miles east of Santa Barbara, he says:

> In this part of the chain the volcanic forces can not be said to be quiescent as yet. On Dr. Robbin's ranch . . . . occasionally fire, smoke, and sulphurous vapor has been emitted, from fissures in the rock, in large quantities within a few years past. A similar volcanic vent exists at Rincon.

The fire at Rincon Point referred to above, and which went popularly by the name of the "Rincon Volcano" was still active in 1890, when the vicinity was visited by Professor H. C. Ford.[2] In the course of his description he says,

> I found hot gases bursting from numerous apertures in the shales, accompanied in some cases by melted bitumen that hardened in concretionary masses upon cooling. . . . . Crystals of sulphur had also formed upon all objects near the issue, and naptha appeared to be present. A few years ago a tunnel was run into the cliff at its base to a depth of 200 feet in search of oil. At this depth the workmen were obliged to cease operations in their endeavor to penetrate farther on account of the great heat. Upon entering this tunnel I found the temperature still high but noticed only weak sulphurous gases. Near the entrance for 50 or 60 feet the roof and sides were thickly covered with attenuated colorless crystals of epsomite hanging in tufts and masses. . . . . When the excavations of the Southern Pacific Railway were made at a point a mile farther west from the locality just described, a similar issue was discovered, and upon touching a match to the gas, combustion ensued and continued, notwithstanding vigorous efforts were made to extinguish it. . . . . During the summer of 1888, Mr. Richardson, who resides a short distance below the Rincon "fire wells," was startled by loud reports in their direction and upon visiting the locality observed flames issuing to the height of several feet from the apertures. Parties from Santa Barbara visited the spot upon hearing of this outburst and confirmed Mr. Richardson's observations.

The same writer mentions a similar "solfatara" on the San Marcos Ranch in the Santa Ynez Valley, and says, "Distributed over the surface were eight or ten apertures from which rose visible sulphurous fumes to the height of from two to three feet." He found the tem-

[1] *Explorations and Surveys for the Pacific Railroad*, Vol. VII, p. 71, Washington, 1857.

[2] *Bull. Santa Barbara Soc. Nat. Hist.*, Vol. I, No. 2, October, 1890.

perature of the gases upon their issue "to be so high that the hand could not for a moment bear the heat." It is not known to the writers whether these fires are still burning.

TYPICAL OCCURRENCES OF BURNT SHALE

The Santa Maria oil district in northern Santa Barbara County is rich in outcrops of rose-colored shale and other products of the burning process, these occurring in eight or ten separate localities. The best examples are along the ridge bordering the Santa Maria Valley some eight miles southwest of Santa Maria; on the north and south sides of Graciosa Ridge, a similar distance south of that town; and on Redrock Mountain, four miles southeast of Los Alamos. In each of these regions every stage of alteration is exhibited from the slightly discolored shale to hard slag-like rocks of varying shades of red and black (see Fig. 2). The area of altered shale in the different localities varies from a small one of some hundred square feet to one of half a square mile or more, as at Redrock Mountain. They are in every case surrounded by unaltered, usually soft, white, diatomaceous shale, which in the majority of cases shows the planes of stratification (see Fig. 1). No case was observed in which a sign of stratification was left in the baked shale. In every case the shale in the neighborhood is bituminous and asphalt deposits are usually adjacent.

The largest area of altered shale in this region is on the summit and surrounding ridges of Redrock Mountain south of Los Alamos. This is the highest of the hills in the basin region between the San Rafael and Santa Ynez Mountains, being 1,968 feet above the sea, while the usual height of the summits round about is from 1,000 to 1,500 feet. It seems to owe its prominence, at least in part, to the metamorphosed shale forming its summit. In the case likewise of the 800-foot hill on the southeast side of the Southern Pacific Railroad coast line at Schumann Pass, the capping of volcanic-looking rock of this same character seems to have caused the topographic relief. The metamorphism in these cases probably took place a long time ago. At Redrock Mountain, in places in contact with the altered shale, are great deposits of asphalt and a large area of shale impregnated with bitumen.

DEPTH TO WHICH ALTERATION HAS EXTENDED

The depth to which alteration has extended below the surface in these cases is difficult to determine. A cliff of burnt shale 50 to 100 feet high is exposed 4½ miles due south of Guadalupe, and the difference of elevation of points in the Redrock Mountain neighborhood where the altered rock outcrops amounts to several hundred feet.

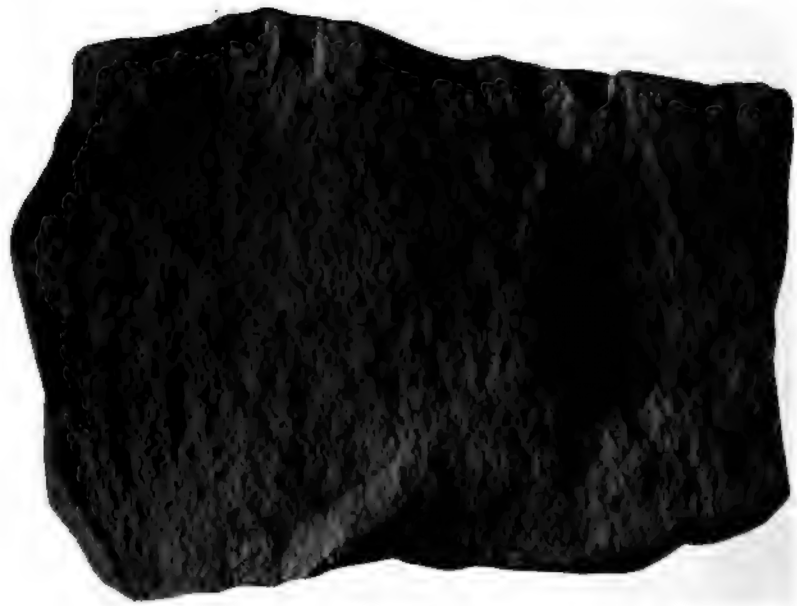


FIG. 1.—Hand specimen of typical diatomaceous shale from the Santa Maria oil district, Santa Barbara County, California (slightly reduced).

That such metamorphism of the shale has not been solely a surface phenomenon is shown by the fact that burnt shale has been found on drilling at considerable depths. Mr. Orcutt, of the Union Oil Company, exhibited samples of red shale, coming from depths of 950 to 1,040 feet below the surface in Hill well No. 1 in the Lompoc Field, which are identical in appearance and texture with the burnt shale elsewhere. Traces of petroleum were associated with the upper stratum of burnt shale in this instance. There are numerous wells in the Santa Maria field in which red shale, doubtless burnt, was met with at depths varying between 90 feet and 330 feet below the surface. The hardening consequent upon the burning has sometimes rendered the rock difficult to drill through.

LITHOLOGIC CHARACTER

The burnt shale exhibits all stages of change from slight induration and discolorization due probably to oxidation of iron, to extreme hardening, and partial fusion. When slightly altered the normal white shale assumes a light pink color. From this stage it passes through various shades of rose and brick red and deepens in color to

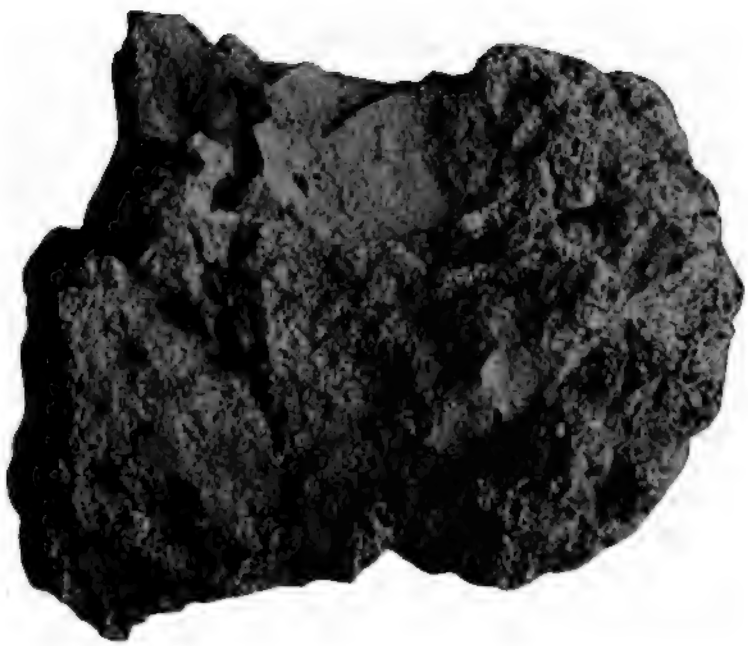


FIG. 2.—Hand specimen of a similar shale after metamorphism by burning (slightly reduced).

a reddish, bluish, or greenish black or true black. In the advanced stages of change it becomes a rough, brittle, reddish, porous slag just like vesicular lava, like that shown in Fig. 2, or a very hard, compact, dark and dull-colored rock looking somewhat like a compact igneous rock. It is not crystalline, but the texture is variable so as to give a patchy appearance to surfaces. In one place it will be compact and black, nearby full of irregular cavities surrounded by patches of different colors, or again vesicular and reddish. Whereas the weight

of the original shale is slight, the lighter varieties having a specific gravity less than that of water, the excessively burnt shale is very heavy. The material has evidently contracted to much less than its original volume, the angular cavities and irregular vesicles being one consequence of this contraction.

Under the microscope the more advanced stages appear as having an exceedingly fine-grained, amorphous, porous ground-mass discolored with a reddish brown or gray stain. Black filaments and dots appearing like carbonaceous material are common. Exceedingly minute rounded and irregular grains scattered through the whole, but forming no appreciable proportion of it, are the only portions visible under crossed nicols. They extinguish four times in a revolution of the field, and are probably clastic quartz grains. These are characteristic of the unaltered shale as well.

Mr. George H. Eldridge remarks[1] on an occurrence of burnt shale in the Santa Maria field near the old Blake asphalt mine south of Graciosa Ridge. He says, "The shale now appears red, ash-like to hard and clinker-like, glazed or silicified; bodies of bitumen contained within this have the appearance of a coke, as though derived from the solid fixed carbon of the petroleum."

The likeness of varieties of the burnt shale to volcanic rocks is indicated by the fact that Thomas Antisell in his account of the geology of the Coast Ranges in the Pacific Railroad Report,[2] describes "scoriaceous" and "amygdaloidal lava," "whitish-gray, hard trachytic rock," "volcanic," and "igneous rocks" in the region of the Santa Ynez River, evidently having reference to the burnt shale. He considered it to be in eruptive masses, forming the oldest and axial rocks of the hill ranges, whereas it is part of the Monterey shale formation which overlies the basement formations. He regarded the associated diatomaceous shales in some places, although not in others, as "magnesian" and "tremalite" rocks of igneous origin. He refers to the places where the shale is burning as examples of present volcanic activity.

[1] "The Asphalt and Bituminous Rock Deposits of the United States," *Twenty-second Annual Report, U. S. Geological Survey*, 1901, Pt. I, p. 428.

[2] *Explorations and Surveys for the Pacific Railroad*, Vol. VII, pp. 65–72. Washington, 1857.

CAUSE OF THE ALTERATION

There can be little doubt that the burnt shale is in all cases the result of heat produced by combustion of the hydro-carbon contents of the shale. The phenomenon is confined to the Monterey shale, which is the source of a large part of the California petroleum, and to those regions in which this formation is extremely bituminous. The shale in such places is frequently impregnated with petroleum and the cracks partially filled with it. The altered shale areas are almost invariably situated in the vicinity of oil seepages, which usually connote a fractured condition of the rocks such as would allow fire to spread and be supported. The observance of fires actually in progress in the shale and the changes that have taken place in the rocks round about—changes in every way similar to those in localities of the metamorphosed shale where no fire exists at present—gives the best of clues to the manner in which the shale has been baked in other cases. It is difficult to conceive of a source of heat sufficient to cause local baking of the shale in otherwise unaltered strata at a depth of 1,000 feet below the surface in such a case as has been mentioned. Probably there, as on the surface, it was due to ignition of bituminous material. It is probable that fire started in the petroliferous shale at the surface and threaded its way downward along cracks partially filled with bitumen or gaseous hydrocarbons. The failure to smother the fire in the shale on Graciosa Ridge, as previously mentioned, indicates that such fires are able to survive with a limited air supply. On the other hand if the above theory is correct it indicates that a considerable amount of oxygen may be present in the rocks at such a depth.

The cause of ignition may be kindled fires, lightning, or the spontaneous combustion of the hydrocarbons or surface vegetation. Many of the recent cases of burning are directly traceable to the first cause, but for those which may have taken place before the advent of man, either the second or third cause will have to be invoked.

Burnt shale was noticed by J. D. Whitney in the vicinity of Santa Barbara, and its origin rightly interpreted. He says of it:

> About five miles southeast of Carpinteria, the rock presents exactly the appearance of having had the bituminous matter burned out of it; it assumes various

colors, such as bright red, rose, brown, yellow, and cream color and it appears to have been partially fused in some places.[1]

And again he remarks, referring to the same region.

In some localities the rock has evidently been on fire, and the bituminous matter having been burned out—the operation continuing for several years, as it is said—the slates are left of various shades of red, produced by the oxidation of the iron.[2]

Burnt-shale areas occur in many places besides in Santa Barbara County. Mr. G. H. Eldridge[3] makes the following comment on its occurrence and origin in Ventura County where especially good examples are to be found south of the valley of the Santa Clara River on Oak Ridge and the crest of South Mountain.

The siliceous shale and "chalk rock" forming the crest of the mountains south of the Santa Clara have at many points been burned to a bright red color. The fuel which supported such fires was perhaps the originally contained petroleum.

Opposed to this view, however, is the very considerable depth to which the shale has been altered to a brilliant red lava-like rock; hence it may be inferred that spontaneous combustion alone has brought about the modification.

RANGE IN TIME OF THE PHENOMENON

As already mentioned, the marked influence of the hardened shale on the topography in certain instances points to its origin in those cases a long time since. The age of some of the burnt shale areas is further shown by the presence of numerous fragments of it at a depth of at least ten feet below the surface in horizontal beds of Pleistocene age. These beds are of sand, clay, and rough gravel, and form the low hills between Guadalupe Lake and the high hills to the west. The fragments of shale are little worn and evidently of local derivation; having very possibly come from the cliffs before mentioned south of Guadalupe. The fact that the Monterey shale underwent this kind of baking in Pleistocene times indicates further that the accumulation of the oil and its dissemination in the surface rocks took place, or was taking place, before the latest orogenic movements in this coastal region.

[1] "Geol. Survey of California," 1865, *Geology*, Vol. I, p. 126.

[2] *Ibid.*, p. 131.

[3] G. H. Eldridge and Ralph Arnold, "The Santa Clara Valley, Puente Hills and Los Angeles Oil Districts," *Bull. 309, U. S. Geol. Survey*, p. 22, 1907.

THE SUDBURY LACCOLITHIC SHEET

A. P. COLEMAN
University of Toronto.

TABLE OF CONTENTS

INTRODUCTION

The Sudbury mining region has for nearly twenty years attracted the attention of mining engineers and geologists because of its great deposits of nickeliferous sulphides associated with a special eruptive rock. Recent field-work carried out by the writer and his assistants for the Bureau of Mines of Ontario has demonstrated that the region is even more interesting from the geological side than had been supposed; since the ore bodies form part of the edge of a great eruptive sheet having a length of 36 miles, a breadth of 16 miles, and a thickness of a mile and a quarter. While cooling this molten sheet underwent magmatic segregation in which gravitation played a large part, so that the heaviest ingredients, the ores, sank to the lowest points, merging upward into norite, the next heavier rock, which passes upward into granite, the lightest rock of the sheet.

Details of the geology of the region may be found in a final report by the writer recently distributed by the Bureau of Mines;[1] but as

[1] *Bureau of Mines* (Ontario, 1905), Part III.

many geologists do not receive these reports, it is proposed to give here a condensed account of the nickel-bearing eruptive and its general relationships to the rocks of the region.

It was quickly discovered by prospectors for nickel that all the ore deposits are associated with bands of a particular basic rock, at first called diorite, but later found to be norite. The district was mapped in 1890 by Dr. Bell, with Dr. Barlow and other assistants, and their work brought out clearly some of the features just mentioned. Two main bands of the nickel-bearing eruptive were indicated, a northern and a southern, or main, range, running with some interruptions parallel to one another in a northeasterly and southwesterly direction.[1] In 1893 a great advance was made in our knowledge of these relationships by Professor T. L. Walker, who showed that the norite associated with ore passes into micropegmatite, and also that the transition from norite to granite takes place from south to north in the main range, and in the reverse direction in the northern range.[2]

My own field-work, begun in 1902, proved that the two ranges are connected at the ends, forming an irregular oval, and as the results of three summers in the field, the upper and lower boundaries of the sheet were mapped, the only important gap occurring for about two miles at the east end, where the solid rocks are concealed by drift. This work has proved also that the sheet is basin-shaped, since the lower or basic edge everywhere dips inward; and that the ore deposits are all at the lowest points of the basic edge, showing that segregation took place by the aid of gravity.[3]

Dr. Barlow's report, which appeared in 1904, confirms these results as far as the southern range is concerned and gives an exhaustive account of the petrography of the region and the development of the nickel industry. It should be consulted by anyone interested in nickel.[4]

SHAPE AND SIZE OF THE SHEET

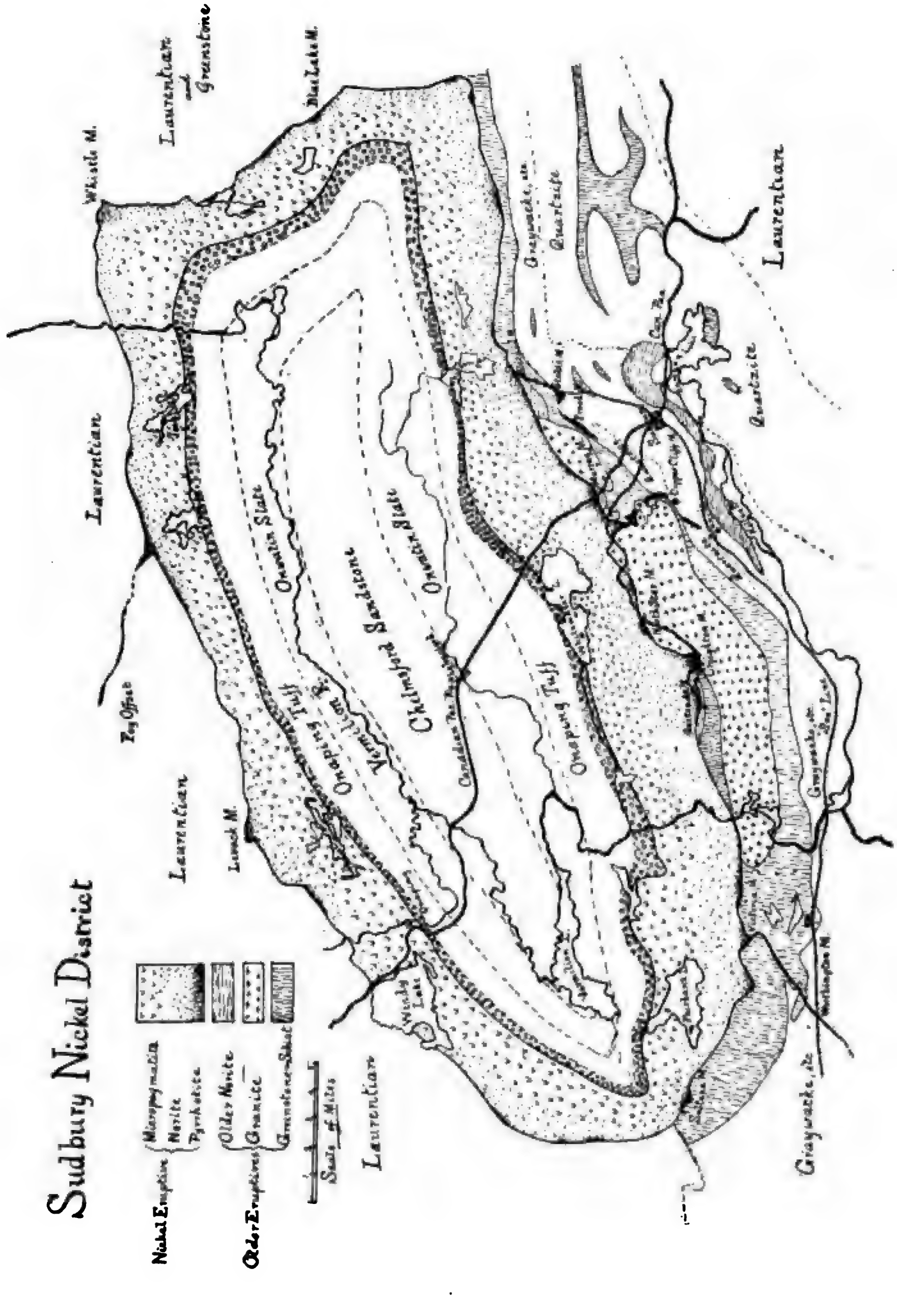
The norite micropegmatite sheet forms an irregular synclinal basin, somewhat boat-shaped or spoon-shaped, to borrow Dr. Daly's

[1] *Geological Survey of Canada*, 1890, Part F.

[2] *Quarterly Journal of the Geological Society of London*, Vol. LIII, pp. 40–46.

[3] *Bureau of Mines*, 1903, pp. 276–78, and 1904, pp. 193, 194.

[4] *Geological Survey of Canada*, 1904, Part H.


Sudbury Nickel District
Nickel Eruption
Micropegmatite
Norite
Pyrrhotite
Older Eruptives
Older Norite
Granite
Greenstone-Schist
Scale of Miles
Laurentian
Laurentian and Greenstone
Onaping Tuff
Onwatin Slate
Chelmsford Sandstone
Vermilion R.
Quartzite
Graywacke, etc.
Windy Lake

apt expression, the bowl of the spoon being filled with sedimentary rocks everywhere dipping inward. It rests upon the steeply upturned edges of Huronian schists as well as on Laurentian gneiss and some eruptive masses later than the rocks just mentioned. It is evident that the sheet separates two series of rocks having entirely different attitudes, and that originally the upper sediments rested uncomformably on the lower rocks. In Dr. Daly's "Classification of Igneous Intrusive Bodies" it corresponds to an "interformational laccolith."

As will be seen from the accompanying map, the sheet has an outcrop of irregular width varying from five-sixths of a mile at the narrowest point of the northern range to four and one-fifth miles at the widest part of the main range. The average width is two miles and a half. As exposed at the various mines and prospects the basic edge dips inward, at angles from 20° to 64°; while the sedimentary rocks overlying the sheet have an average dip of about 30°.

Accepting 30° as the correct average dip, the thickness of the sheet is a mile and a quarter. The syncline is 36.2 miles long by 16.6 miles wide, with an average width of 13.6 miles; so that its solid contents must be about 600 cubic miles, if the concealed parts are as thick as the exposed edges.

The upturned edges of the sheet have no doubt undergone great erosion, since the region has been exposed to erosion since Cambrian times. If we suppose that a width of three miles has been removed all around, the original mass must have been 1,000 cubic miles. In magnitude, then, the Sudbury laccolithic sheet far surpasses even the great sills described by Dr. Daly from British Columbia.

As the term "sill" seems to imply a flat-sided body rather than a curved one, and as sills regularly lie between two layers of sedimentary rock, I have preferred the non-committal term "sheet" for the Sudbury eruptive, which is synclinal and rests on a somewhat irregular surface made up of a complex of schistose and eruptive rocks.

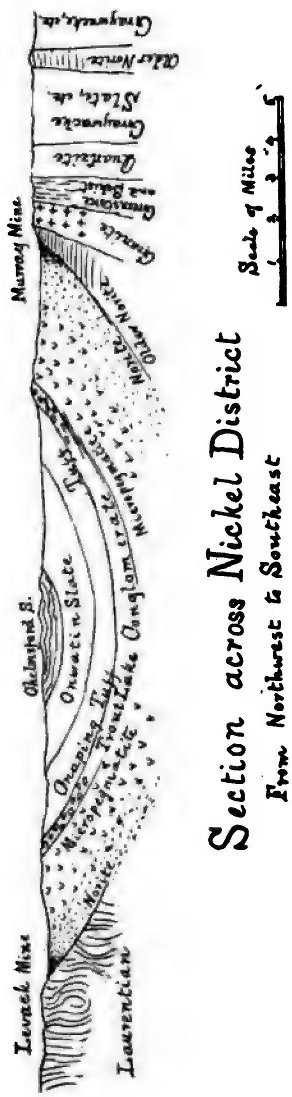
CAUSE OF THE SYNCLINAL FORM

One naturally asks why the eruptive sheet with the overlying sedimentary series should form a synclinal basin. As the surrounding and underlying rocks show hardly any sympathy with this synclinal arrangement, we cannot assume that it is due to lateral mountain

building thrusts, but must look for some other cause. The most probable supposition is that the source of the magma was immediately beneath the longer axis of the area, which is now basin-shaped, but was then flat and undisturbed.

The original molten mass was probably much thicker, but also much narrower, than the present laccolithic sheet. When it ascended and spread out widely between the upper sediments and the less regular rocks beneath, there was a collapse, since the schists and older eruptives below had lost their central support. This shows itself very plainly in the shattered and faulted character of the rocks underlying the sheet. The collapse gave rise to the roughly synclinal basin occupied by the eruptive, while the overlying sedimentary rocks settling into the still plastic magma beneath formed a more regular syncline.

The process of collapse and adjustment was probably a very slow one, beginning with the earlier upward movements of the magma, and ending only when the whole mass had cooled so far as to lose its plasticity.



Section across Nickel District
From Northwest to Southeast

PETROGRAPHY OF THE NICKEL ERUPTIVE

The petrography of this great sheet has been touched on by numerous writers, particularly since Baron von Foullon proved that the fresh rock associated with the nickel ore contains hypersthene instead of hornblende, and is therefore norite and not diorite, as it was named at first. Details of the petrography may be found in

Professor Walker's paper[1] and the reports of Dr. Barlow[2] and the present writer on the nickel region;[3] so that it will be unnecessary to give an elaborate account of the various sections made across the edge of the sheet. In general it may be said that where the outcrop is broad, as near the Creighton and Murray mines, the norite makes up about half of the section; but where the outcrop is narrow, as at some parts of the northern range, the basic portion may be nearly absent. The micropegmatite forming the upper portion of the sheet is more nearly uniform in thickness than the norite beneath The ore deposits, consisting chiefly of pyrrhotite with a comparatively small amount of pentlandite, the real nickel-bearing mineral, and chalcopyrite, are clearly parts of the eruptive and may be looked on as excessively basic phases of the lower edge of the sheet. The ore is not continuous around the whole margin, however, but occupies especially the lowest points, where the outcrop of the eruptive is wide; being largely or entirely absent from narrow parts.

In crossing a wide outcrop of the eruptive, as at the Creighton or the Murray mine on the southern range, one finds on the southeast side massive pyrrhotite resting against granite or lower Huronian rocks and more or less penetrating them as veinlets, or inclosing fragments of them. Even the massive ore contains small portions of the norite minerals, especially labradorite; and a few feet or yards to the northwest the silicates increase in quantity until, when there are about equal amounts of silicates and sulphides, the rock may be called pyrrhotite-norite. Beyond this the sulphides diminish, until within one or two hundred feet there are only blebs of pyrrhotite scattered through the norite; and at length norite without sulphides. From this point for a mile or two northwest the norite undergoes little change, then becomes reddish in color, merging into micropegmatite, which does not vary greatly till the acid edge is reached.

On narrow parts of the northern range true norite is almost absent, and an intermediate rock containing some quartz, orthoclase, and pegmatite forms the bottom of the sheet.

The norite of the basic edge of the eruptive varies considerably

[1] *Quarterly Journal of the Geological Society of London*, Vol. LIII, pp. 40–46.

[2] *Geological Survey of Canada*, Vol. XIV, Part H, 1904.

[3] *Bureau of Mines*, Ontario, Vol. XIV, Part III, 1905.

from point to point even along the broader parts of the range, but it will be sufficient for our purpose to describe the characters of an average fresh example. It should be remarked that fresh norite is oftenest found close to large ore bodies and may be shotted with particles of ore. On the southern range the rock is dark gray, coarse-grained, with blebs of bluish quartz and large flakes of biotite. On the northern range it is lighter gray, but does not differ in composition.

In thin sections the rock is found to contain labradorite to the extent of at least one-half—often more—hypersthene about a quarter, and smaller amounts of monoclinic pyroxene, hornblende, and biotite, with quartz, titaniferous magnetite, apatite, and often sulphides as accessory minerals. The labradorite is usually very fresh, pale brown from dusty inclusions on the southern range, and clear on the northern, with hypidiomorphic forms, sometimes platy. The hypersthene forms rough prisms with good pleochroism, but without scale-like inclusions. The monoclinic pyroxene seems closely related to the hypersthene in appearance, is pleochroic, but has a small or fairly large extinction angle. One is tempted to think of the hypersthene as merely augite with the extinction angle reduced to zero.

Of the minor minerals hornblende occurs mostly as secondary rims about the pyroxenes, while quartz forms small wedges between the feldspars, and occasionally has pegmatitic intergrowths with feldspar.

The typical rock just described is not found everywhere, since usually the ferromagnesian minerals are completely changed to bastite or hornblende accounting for the older designation of the rock as diorite.

At the Creighton mine the norite contains notable amounts of quartz, orthoclase, and microcline, partly intergrown as micropegmatite, but this is unusual. The country rock at this point is gneiss, in general free from micropegmatite, but sometimes showing a rim of coarse pegmatite against the norite, suggesting that the basic magma has interacted with the neighboring rock, perhaps absorbing part of it.

Thin sections of the pyrrhotite-norite found adjoining the ore bodies are often surprisingly fresh, in several of the two dozen slices

made, even the hypersthene showing little or no trace of rearrangement. The association of the pyrrhotite and chalcopyrite with the ordinary rock-forming minerals is a matter of some interest, so that the relationships of the two kinds of material in the freshest sections will be described.

The pyrrhotite and chalcopyrite occur generally together, the first being the more common of the two, and they often form sharp-edged masses of a round or angular shape completely inclosed in silicates. They most commonly accompany biotite, which may form a fringe around them, but are rather often found in hypersthene also. In many cases the sulphides lie beside solid portions of magnetite, and in one slide magnetite incloses pyrrhotite.

In the freshest sections there is no hint of a splitting-up or decomposition of the silicates inclosing sulphides, and no visible channel by which the sulphides could arrive at their present position. The edges of the hypersthene prisms are often as square and sharp against pyrrhotite as against any of the silicates of the rock, and the whole appearance suggests a nearly contemporaneous origin of sulphides, oxides, and silicates, the more basic minerals generally keeping together.

In the dikelike offsets from the basic edge of the sheet norite and ore are found mixed, the rock having the same general character as the main range, though finer-grained and more greatly weathered.

The intermediate stages between norite and micropegmatite consist of mixtures of the constituents of the two rocks, but the hypersthene is generally replaced by hornblende.

The acid phase of the sheet is quite variable, but always contains intergrowths of quartz and feldspar. The feldspars include orthoclase and also plagioclases such as andesine, while the dark minerals are hornblende, biotite, and some magnetite, but no pyrrhotite. The micropegmatitic structure ranges from very coarse intergrowths to almost submicroscopic varieties, where a small, sharply outlined crystal of andesine is inclosed in a wide border of plumy intergrowths in which the character of the feldspar cannot be determined even by high powers of the microscope. The feldspars of the acid edge are often platy, giving a hint of trachytic structure, as, for instance, near Onaping. In other cases the rock is more granitoid-looking;

but there are examples near each end of the basin where squeezing and shearing have gone so far as to produce schists. As these are often greenish in color and quite unlike granite or gneiss, they proved very puzzling in the field, but the microscope shows that they consist mainly of plumy micropegmatite with a little chlorite, and an analysis gives a composition similar to the granitic portions of the acid edge, as may be seen from column nine of the table of analyses on a later page.

Judging from its mineralogical composition, most of the acid portion of the eruptive sheet is grano-diorite, but parts of it have so little plagioclase that they might be called granite, while other parts with comparatively little potash feldspar might be called quartz-diorite.

RELATION OF THE BASIC EDGE TO THE ROCKS BELOW

As may be seen from the map, the basic edge of the laccolithic sheet is, in places, quite irregular, with inward projections of the country rock and bays directed outward. From some of the funnel-shaped bays narrow bands of norite reach out into the country rock, sometimes for several miles, but usually with gaps in their continuity. For these projections I have used the term "offset" rather than "dike," since the latter implies a continuous sheet of eruptive rock with somewhat uniform width. One or two of these offsets may be described to bring out the relations of the nickel eruptive to the rocks on which it rests.

Where the country rock extends like a promontory into the basic edge there are no ore bodies, but where the opposite occurs, the norite pushing baylike into the country rock, as at Creighton, large ore bodies are found. When such a bay opens outward into an offset, as at Copper Cliff, the ore forms only small deposits along the sides of the funnel, but larger bodies where interruptions break the offset. In the Copper Cliff offset, for example, we find first a wide bay, with three small masses of ore along its edges; then a narrow band extends southeast for a third of a mile, ending in No. 2 mine, a body of ore 230 feet in length along the offset, and half as wide. This chimney-like deposit has been worked to a depth of 400 feet, and probably goes much deeper.

To the south of this the offset is cut off for a third of a mile, but reappears at the famous Copper Cliff mine, with an ore body 75 to 200

feet in length along the offset and 50 to 90 feet across it, and having a known depth of 1,000 feet. About 700 yards west there is a narrow band of norite with some ore running south for about a quarter of a mile. After another gap of two-thirds of a mile the last outcrop of norite and ore occurs at the Evans mine. The whole length of the offset is more than 4 miles.

It is assumed that all the isolated stretches of norite and ore are either connected by devious channels below the surface, or that they were once connected by portions that have now been eroded away.

One band of norite and ore, that of the Frood and Stobie mines, is of a different kind, showing no point of attachment with the basic edge of the eruptive, but running for 2 miles nearly parallel with it. Here there is probably an underground connection with the main range. The longest offset is from the middle of the northern range, running more than 6 miles to the west.

The basic edge of the nickel eruptive has often a very irregular contact with the rock beneath, frequently inclosing blocks of it and running short distances into it. The offsets are variable in cross-section, and sometimes form curious breccias with blocks of the adjoining rocks, and also of norite of a coarser or finer grain than the matrix. The pyrrhotite takes its part in these relationships very much as the rock does, but it probably remained fluid longer than the norite and has penetrated more intricately into the rock beneath. Often both norite and rock grow finer-grained at the edge, showing that the adjoining rock was colder and chilled the magma in contact with it.

The injection of the magma between the flat-lying upper rocks and the complex of graywacke, schist, and granite beneath occasioned great fracturing and crushing along the lower surface, and in some cases near the southern range there are numerous faults due to the collapse of the rock-floor when no longer supported by the magma which had risen from beneath it. These irregular fractures and faults probably afforded the channels through which the offsets reached their present position.

THE UPPER CONTACT OF THE LACCOLITHIC SHEET

The acid or upper edge of the sheet seems to have caused much less fracturing and fissuring of the rocks in contact with it than the

lower edge; but, on the other hand, has exerted a far greater metamorphic action. No long dikes or apophyses are known to project from the acid edge into the overlying rocks, though some short ones have been observed.

The rocks above the laccolithic sheet are the Trout Lake conglomerate with an estimated thickness of 450 feet, the Onaping tuff, 3,800 feet thick, the Onwatin slate, 3,700 feet thick, and the Chelmsford sandstone, 350 feet thick, giving a total of 8,300 feet of sediments.

The lowest of these formations, the Trout Lake conglomerate, which was in direct contact with the upper surface of the molten sheet, has been strongly metamorphosed; and about half of the next higher one, the Onaping tuff, has been greatly indurated and silicified, though its fragmental character is still distinct. The overlying sediments are comparatively soft and unchanged, having a very modern look; while the Trout Lake conglomerate has been so metamorphosed in many places as to suggest a Laurentian gneiss, and was in fact so mapped in earlier days.

The three upper formations are fairly uniform in thickness, but the Trout Lake conglomerate varies from more than 600 feet to only 20 feet, partly perhaps because of original differences in thickness natural to so coarse-textured a rock as a bowlder conglomerate, but partly also, it is believed, because unequal amounts have been absorbed by the underlying eruptive.

The lower part of the conglomerate has been so completely reconstructed that little can be said as to its original composition except that it inclosed large and small bowlders of granite, and that the matrix had a composition which could be transformed into gneiss.

In less altered parts well-rounded pebbles and bowlders of granite, of quartzite, and of green schist or greenstone are found in a grayish crystalline matrix. Occasionally white quartzite is interbedded with the conglomerate.

The exact boundary of the micropegmatite against the conglomerate is very hard to trace. Often in our field-work when crossing the edge of the eruptive toward the sediments, we would overrun the limit, which could be recognized only by the coarser-textured and redder patches representing granite bowlders.

Thin sections made of hand specimens taken across the boundary

show first the characteristic micropegmatite of the eruptive itself, afterward changing into micropegmatite of a somewhat ruder kind in the matrix of the conglomerate. Near Moose Lake, for example, on the inner edge of the northern range the micropegmatitic character of the matrix continued for 150 paces from the edge, but had disappeared in the specimen from 180 paces. The conglomerate has been so completely transfused and recrystallized as to be easily taken for an eruptive rock containing some coarser patches, and one can properly call the relation one of gradual transition from the eruptive to the conglomerate.

CHEMICAL COMPOSITION OF THE SHEET

From the microscopic characters of the basic and acid phases of the laccolithic sheet given on a former page it will be anticipated that the chemical composition must vary greatly. These variations were first demonstrated by Professor Walker in his paper on the region, and his analyses will be quoted here with the addition of several made for the Bureau of Mines. In the table given below analyses 1 to 4 are from near the basic edge, 5 and 6 from intermediate points, and 7 to 10 from near the acid edge.

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
SiO_2	49.90	51.52	56.89	60.15	64.85	68.48	61.93	67.76	68.95	69.27
Al_2O_3	16.32	19.77	19.39	18.23	11.44	12.70	13.03	14.00	12.74	12.56
Fe_2O_3	......	.47	.38	1.51	2.94	2.41	.56	......	.46	2.89
FeO	13.54	6.77	7.11	6.04	6.02	4.50	8.00	5.18	5.15	4.51
MgO	6.22	6.49	2.11	3.22	1.60	.74	1.76	1.00	1.57	.91
CaO	6.58	8.16	8.11	4.01	3.49	1.41	4.02	4.28	1.72	1.44
Na_2O	1.82	2.66	3.31	1.28	3.92	3.72	3.18	5.22	3.80	3.12
K_2O	2.25	.70	1.04	1.68	3.02	3.36	2.80	1.19	3.28	3.05
H_2O	.76	1.68	1.35	.55	.78	1.13	1.95	1.01	1.50	.76
TiO_2	1.47	1.39	.43	1.34	......	.61	.84	.46	.43	.78
P_2O_5	.17	.10	.11	.23	.24	.20	.32	.19	.20	.06
MnO	trace	trace	.30	.29	trace	.05	.18	trace	.13	trace
BaO	......	......	......	.25	......	......	trace	......	trace	......
SrO	......	......	......	.14	......	......	......	......	......	......
NiO	......	......	......	.17	......	......	......	......	......	......
Cu	......	......	......	.16	......	......	......	......	......	......
S	......	......	......	.54	......	......	......	......	......	......
Total	99.03	99.71	100.53	99.79	98.30	99.31	98.76	100.29	99.93	99.35
Specific gravity	3.026	2.832	2.834	......	2.788	2.673	2.757	2.709	2.694	2.724

In the above table No. 1 and No. 2 are from the basic edge of the southern range near Blezard mine; analyst, Professor T. L. Walker. No. 3 is from the basic edge of the northern range near Onaping; analyst, Mr. E. G. R. Ardagh. No. 4 is from the Creighton mine near the ore body; analyst, Mr. M. T. Culbert. No. 6 is of a syenitic-looking specimen from near the middle of the Onaping section; analyst, Mr. Ardagh; and No. 7 is by the same gentleman, of a greenish-gray specimen from the acid edge at Onaping. No. 8 is from near the acid edge of the Blezard-Whitson lake section; analyst, Professor Walker. No. 9 is from the acid edge on the north shore of Fairbank Lake in the southern range, the rock being dark green-gray and somewhat schistose; analyst, Mr. Ardagh. No. 10 is from near the acid edge of the Blezard-Whitson lake section; analyst, Mr. C. B. Fox.

It should be mentioned that No. 4, from the Creighton mine, is exceptional for the basic edge, containing considerable quartz, microcline, and micropegmatite, perhaps absorbed from the adjoining granitoid gneiss.

The two analyses of specimens taken about half-way between the basic and acid sides of the sheet do not differ greatly in composition from analyses of rock from the acid edge itself, and must be looked on as really belonging to the micropegmatitic side of the eruptive. Averaging the first four analyses as representing the norite, and the last six as representing the micropegmatite, we get the following results:

	Basic Average	Acid Average	Total Average
SiO_2	54.615	66.873	61.970
Al_2O_3	18.437	12.745	15.022
Fe_2O_3	.590	1.543	1.362
FeO	8.365	5.562	6.683
MgO	4.510	1.263	2.542
CaO	6.715	2.727	4.322
Na_2O	2.267	3.827	3.203
K_2O	1.417	2.787	2.239
H_2O	1.085	1.188	1.147
TiO_2	1.157	.502	.763
P_2O_5	.152	.202	.182
MnO	.122	.060	.065
Minor substances	.320	......	......
Total	99.752	99.279	99.500

The total average was obtained on the basis of two parts basic rock to three parts of acid rock, which corresponds roughly to the field relations. The ore deposits, really integral parts of the basic edge, have been left out in the calculation, since the percentage which they form of the whole eruptive is relatively small, though about 2,500,000 tons of ore have already been mined and many millions more are known to exist. Professor Vogt refers to the Sudbury gabbro as containing originally about 0.05 per cent. of the ore, which may serve as a not improbable guess at the quantitative relations.

According to the new classification of eruptive rocks, the average basic side of the eruptive may be called Harzose, and the acid side Adamellose. The norm for the two phases is as follows:

		Basic		Acid	
Quartz		9.24		20.76	
Orthoclase		8.34		22.24	
Albite		19.39	51.92	31.06	37.73
Anorthite		32.53		6.67	
Diopside	$CaO \cdot SiO_2$	....		2.44	3.99
	$MgO \cdot SiO_2$	....		.70	
	$FeO \cdot SiO_2$	....		.85	
Hypersthene	$MgO \cdot SiO_2$	11.30	24.10	2.40	8.74
	$FeO\ SiO_2$	12.80		6.34	

The norm of the rocks as worked out above, omitting minor ingredients, corresponds fairly well with the mode in the norite of the basic side, except that monoclinic augite replaces some of the hypersthene. In the average acid phase of the eruptive pyroxenes hardly occur, being replaced by hornblende and biotite.

CAUSES OF THE DIFFERENTIATION

In my report on the Sudbury nickel region it was suggested that the differentiation of the ore from the rock, and of the norite from the micropegmatite, is mainly due to gravitation. The sulphides are of course far heavier than norite, and the norite is heavier than the micropegmatite; though in the latter case the difference in specific gravity is not so striking. When one observes how the ore has constantly accumulated in the hollows of the floor on which the norite rested, penetrating all the fissures of the rocks beneath, the conclusion seems irresistible that gravity played the main part in its segregation.

There are no ore bodies and hardly any smaller aggregations of ore in the norite above the basal edge; all have settled to the bottom.

The gravitational segregation of rather acid norite from rather basic micropegmatite seems to me on reflection not so certain, though the factor of time is in favor of it. The sediments above the eruptive sheet, without allowing for later erosion, formed a blanket 8,300 feet thick above the molten rock, and the vast mass of the sheet itself, more than 6,500 feet in thickness, must have conduced to excessively slow cooling. There are no certain means of estimating the original temperature nor the rate of cooling; but that the magma was very fluid when it spread out at first is shown by the way it has penetrated all the devious passages of the offsets described on a former page. During the hundreds of thousands of years required for cooling under the conditions mentioned there was time for even slow movements of segregation to accomplish great results.

On the other hand, the theory of stoping should be considered. At the time the field-work was done in the Sudbury region my attention had not been called to this mode of accounting for the micropegmatite, and no observations were made to test its applicability; but the analogous occurrences described by Dr. Daly in southern British Columbia, and his interpretation of Professor Bailey's observations at Pigeon Point on Lake Superior are very suggestive.[1] I have seen no direct evidence of stoping on a large scale from the overlying conglomerate, but have little doubt that the process was to some extent a factor in producing the micropegmatite. The very unequal thickness of the Trout Lake conglomerate from point to point may perhaps be accounted for by unequal stoping.

The peculiar features of the contact, where the boundary between the eruptive and the sediment vanishes, so that there is a real transition between the two, seem better explained by penetration and progressive solution of the conglomerate by the eruptive. It is quite possible, however, that at first much of the conglomerate was stoped away in blocks, sinking deep into the magma and becoming com-

[1] *American Journal of Science,* Vol. XV (1903), pp. 269 ff.; "The Okanagan Composite Batholith," *Bulletin of the Geological Society of America,* Vol. XVII, pp. 329 ff.; "Differentiation of a Secondary Magma through Gravitative Adjustment," Sonder-Abdruck aus der *Festschrift zum siebzigsten Geburtstage von Harry Rosenbusch.*

pletely digested, while later the eruptive became too viscid to allow blocks to sink, but worked on the overlying rock by heated vapors or solutions, causing the remarkable blending of the eruptive with the conglomerate. As the rock above became heated it would lose in specific gravity, until ultimately it might not have sufficient weight to sink into the magma, which was all the time growing cooler and heavier.

Another factor which may be of importance is the gradual change in composition of the upper part of the magma as it absorbed materials richer in silica, whether by digestion of sunken blocks stoped from above, or by direct solution of overlying rocks. It is well known that the more siliceous lavas are much less fluid when near their melting-point than basic lavas, so that the upper part of the sheet may be supposed to have become less and less fluid until blocks could no longer sink through the viscid mass.

It may be that all three processes took part in the differentiation of the eruptive, and that magmatic segregation and the rising of the more acid portions proceeded along with the stoping of blocks and the direct absorption of the overlying rocks.

It is worthy of remark that the micropegmatitic structure is found only in connection with the nickel eruptive; the other acid eruptives of the region are quite free from it. Can it be that micropegmatite is a structure specially belonging to rocks where basic magmas have stoped down and digested or otherwise absorbed more acid rocks? Dr. Daly's sills and the Pigeon Point rocks seem to support this as well as the Sudbury sheet.

EARLIER AND LATER DERIVATIVES OF THE MAGMA

Basic norite.—Though the nickel-bearing eruptive is by far the most important mass of igneous rock in the region, there are several other eruptives that appear to have split off from the same magma at earlier or later times, and these may be more briefly described. They include an older norite which very frequently underlies the nickel-bearing norite, though of a very different type; and certain granites which are intimately associated with the laccolithic sheet.

From point to point for several miles along the southern edge of the main range there is a complex mass of fine-grained norite and

greenstone, often with "pillow structure" and amygdaloidal phases, suggesting surface lava flows, which seems to have been an early eruption from the hearth of the nickel-bearing rock. It is, however, far more basic, containing no quartz nor micropegmatite. It is often quite fresh and in thin sections is found to consist of hypersthene or enstatite, a monoclinic pyroxene, plagioclase (bytownite), and magnetite in small equidimensional grains or imperfect crystals. Here again the monoclinic pyroxene is often pleochroic, and all varieties occur linking the monoclinic to the orthorhombic form. The two pyroxenes make up, as a rule, more than half the section, and the magnetite perhaps a twentieth, the rest consisting of short, stout crystals of plagioclase, with two or only a few twin lamellae.

An analysis by Mr. J. A. Horton shows the following results:

SiO_2	46.69
Al_2O_3	14.23
Fe_2O_3	2.00
FeO	12.86
MnO	.11
MgO	8.15
CaO	13.32
Na_2O	.98
P_2O_5	.19
TiO_2	1.28
Moisture	.08
Sulphur	.12
Total	99.97
Specific gravity	3.24

This corresponds normally to the following mineral composition:

Bytownite	42.57
Diopside	25.73
Hypersthene	20.76
Olivine	5.34
Titanic iron ore	4.98
Apatite	.34
Pyrite	.27

It is a percalcic rock of the order Gallare, class Salfemane, subclass Salfemone, and may be named Kedebekase.

It is rather curious that pyrite and not pyrrhotite is found in the older norite, which comes closer to the European nickel-bearing norites than the Sudbury nickel eruptive in chemical composition.

Granite.—Varieties of granite, and granitoid gneiss occur in bands along the southern nickel range or at no great distance from it, and are probably connected with the nickel eruptive in origin, representing a very acid phase in contrast with the very basic norite referred to above. The granites, which should not be confounded with the much older granite and gneiss of the Laurentian, are of two kinds, one coarse-grained and porphyritic, the other medium-grained; and apparently of two ages, the coarser variety being generally older than the nickel eruptive, while the finer-grained variety is distinctly younger, since it sometimes penetrates the norite as dikes or irregularly shaped bodies. The oldest of these granites is later in age than the basic norite, since it has carried off masses of it or of greenstones formed from it.

These acid rocks are normal granites with much quartz and microcline, some microperthite and orthoclase, a little oligoclase, a small amount of biotite, and still less muscovite. No micropegmatite has been found in thin sections of these rocks, a point of contrast with the granite of the acid edge of the nickel eruptive. These granites may have been split off from the general hearth by magmatic segregation without stoping or absorption of more acid materials.

An analysis of one of the later, finer-grained granites by Mr. James Horton gives the following results:

SiO_2	75.62
Al_2O_3	11.02
Fe_2O_3	3.17
FeO	1.29
MnO	.12
MgO	.26
CaO	.58
K_2O	5.33
Na_2O	3.11
TiO_2	.16
H_2O	.10
Total	100.76
Specific gravity	2.59

Calculating the normal minerals we find:

Quartz	35.76
Orthoclase	31.14
Albite	26.20
Anorthite	5.06
Hypersthene	.62
Ferric oxide	.63

Probably some of the soda belongs to the orthoclase, since the extinction angles of the plagioclase correspond to oligoclase. According to the new system the rock may be called Omeoze, a dopotassic, peralkalic rock belonging to the order Brittanare, near the boundary of Columbare.

The basic norite and the acid granites just described are thought to have sprung from the original nickel-bearing magma, because they follow so closely the southern edge of the main nickel range; but it must be admitted that they bear little resemblance to the basic and acid phases of the nickel eruptive itself.

The Ramsay Lake gabbro band.—There are, however, a few bands of gabbro which have some points of likeness to the nickel-bearing norite, though they do not occur in close connection with it. The most notable runs for 9 miles parallel to the southern nickel range as a chain of hills separated from it by 3 or 4 miles of Huronian sediments and earlier or later eruptives.

This irregular band of gabbro has pushed up and sometimes partly overturned the stratified Huronian graywacke around its margin, and a few strips of the Huronian run up its flanks at the widest part, suggesting a chain of elongated laccoliths, or possibly the blunt edge of an eruptive sheet having a nearly vertical attitude. As the gabbro differs markedly from the nickel-bearing norite, it is believed that there is no direct connection between them, but that the southern band probably split off from the magma before the main sheet occupied its present position.

The rock is medium- to coarse-grained and usually greatly weathered, though occasionally fresh enough to show its original composition of labradorite, making up about half the sections, diallage and enstatite, the rhombic pyroxene being in somewhat smaller amounts than the monoclinic. There is a very little quartz in interstices

between the plagioclase, and rarely a little micropegmatite. A small amount of pyrrhotite is found at two or three points along the band, but inclosed within the rock, not at one edge as in the main range.

The most interesting feature of this gabbro band is the great white masses of a much more acid rock which are found irregularly along the top of the ridges east of Sudbury and south of Copper Cliff. Some of these masses are 100 yards across and make a very striking contrast with the general green-gray gabbro. They are always inclosed in a margin of very coarse, dark-green hornblende, followed by a zone of mixed hornblende and white feldspar in anhedra several inches across. This phase is succeeded by a zone of white binary granite showing coarse pegmatitic structure, inclosing a central area of almost pure quartz, which may be 50 feet wide.

The hornblende often forms long prisms with a core of white feldspar. The feldspars are oligoclase approaching albite, and orthoclase (or an unstriated plagioclase), and the quartz is glassy, like vein quartz. It is possible that these curious masses, so much richer in silica and alkalies than the rest of the rock, are segregations of the magma separated from the more basic parts somewhat like pegmatite dikes in granite; but they are more probably products of the digestion of large blocks of Huronian quartzite stoped from above. They occur always on the highest points of the gabbro hills.

Very much smaller and less striking masses of a similar kind are found on the basic edge of the main nickel range near Murray mine, close to the bottom of the laccolithic sheet. This fact and the small amounts of pyrrhotite found in the gabbro band just described suggest a relationship between the two rocks. It may be that this gabbro originated in the nickel-bearing magma before segregation had advanced very far, long before the great sheet was injected into its present position.

The three types of rock described above as probably products of differentiation of the main magma, basic norite, acid granite, and intermediate gabbro, were no doubt erupted at very different periods; the gabbro probably coming first, the basic lava flows next, and the granite partly before the ascent of the nickel eruptive and partly after it. None of these rocks occupy areas of more than a few square

miles, so that they are insignificant in amount as compared with the nickel-bearing sheet.

Other eruptives.—There is another mass of eruptive materials, the Onaping tuff, consisting of volcanic ash and lapilli, which may be considered as probably having its source in the original magma; though now spread out as a thick layer between the ordinary water-formed sediments overlying the nickel eruptive. As its area is at least 200 square miles and its thickness two-thirds of a mile, its volume must be about 130 cubic miles; and before it underwent erosion it must have been far more extensive than now. Much of its materials fell as angular fragments of glass, now transformed into chalcedony, serpentine, etc., but mingled with the pyroclastic matter there are a good many well-rounded pebbles and bowlders of quartzite and granite, suggesting ordinary water action. Probably the ash fell into the same body of water which deposited the other sediments of the basin.

An analysis of the tuff by Professor Walker gives the following results:

SiO_2	59.93
Al_2O_3	12.12
FeO	10.56
MgO	5.19
CaO	4.49
Na_2O	3.80
K_2O	.97
MnO	trace
Loss by ignition	1.57
Total	98.63

Its composition is somewhat different from the average of the nickel eruptive as given on a former page, but not so different that we cannot suppose it to have come from that source before the laccolithic sheet had reached its present position. The vitrophyre tuff must have been flung from some volcano of which we no longer have a trace, at a distinctly later time than the lava sheets of basic norite described before, since we have reason to believe that the whole series of sediments of which the tuff forms a part extended over the area occupied by the older norite before the sheet of nickel eruptive was injected between them.

In addition to the comparatively large masses of eruptive rock thus far mentioned, there are later dike-rocks penetrating them all impartially, including large dikes of very fresh olivine diabase, which cross norite, ore bodies, granite, and different kinds of Huronian rocks; and a few small dikes of still later granite which cut the olivine diabase, and are therefore the latest rock in the district except the widespread pleistocene beds of clay, sand, and gravel.

The dike-rocks are separated from the older eruptives by a very long interval of time, and may have no connection with the original nickel-bearing magma.

TIME RELATIONS AND CONCLUSIONS

The oldest rocks of the Sudbury district are mainly sedimentary, including small patches of green schist and banded silica of the Iron formation, belonging to the Keewatin; quartzite, graywacke, and slate of the Lower Huronian, associated with certain schists and greenstones; and Middle Huronian graywacke conglomerate in a small area north of Ramsay Lake.

The granite and gneiss mapped as Laurentian penetrate the sedimentary rocks of the Lower Huronian, and so are later in age; but their relation to the Middle Huronian is not known. The basic norite underlying the main nickel range may be later than the Laurentian, though this is not certain, since the two rocks have not been found in contact. It is later than the Lower Huronian, since it incloses blocks of graywacke and quartzite.

Upon the planed-down edges of these older rocks after a great lapse of time the Trout Lake conglomerate was deposited, followed by the eruption of ash and lapilli forming the thick sheet of the Onaping tuff. Next came the quiet deposit of mud forming the Onwatin slate, and of sand, forming the Chelmsford sandstone.

The age of this series of rocks is uncertain, but they have been looked on as probably the equivalents of the western Animikie, now classed as Upper Huronian. Accepting this classification, the sedimentary rocks range from the top of the Keewatin, the oldest known formation, to the Upper Huronian or Animikie. Next came the flood of nickel-bearing magma spreading as a sheet a mile and a quarter thick between the Trout Lake conglomerate and the lower

rocks; followed by the collapse of the older rocks because of the removal of the molten mass from beneath, the result of this being the synclinal arrangement of the nickel eruptive and the overlying sediments. Some coarse-grained granite or granitoid gneiss was erupted at about the same time or a little before. Not long after the sheet was spread out and solidified, fine-grained granite pushed up through it or beside it; perhaps the last product of the original magma.

The nickel-bearing sheet and the granites just mentioned were post-Huronian in age, perhaps Cambrian or even Ordovician. When all had cooled and hardened, including even the most fluid part of the magma, the ore in the hollows beneath the sheet, fissures cut across all the rocks and were filled with olivine diabase. Last of all a small supply of acid magma penetrated fissures crossing the diabase dikes. The date of this latest of the granites cannot be determined, since there are no fossiliferous rocks in the region.

From the outline just given it will be seen how long and complex a history there is behind the Sudbury nickel ranges and their associated rocks, including sedimentary rocks of four ages, a great sheet of volcanic ashes, norite or gabbro of three ages, granite of at least three ages, and dikes of diabase; the events beginning with the earliest known period of the earth's history and ending in lower Paleozoic times.

If the inferences suggested regarding the relationships of the eruptive rocks are correct, the same magmatic source has provided medium gabbro, very basic norite, rather acid volcanic ash, coarse-grained granite, somewhat acid norite merging upward into pegmatite and downward into nickel ore, and acid fine-grained granite. Whether the much later dikes of diabase and granite should be placed in the succession is doubtful.

The operations included the formation of coarse-grained plutonic rocks of a stocklike kind, flows of lava showing pillow and amygdaloidal structures, the flinging-out of vitrophyre tuffs mingled with some ordinary sediments, followed by the injection of the vast nickel-bearing sheet and its slow differentiation by gravity and the stoping and absorption of overlying rocks; so that the products of the original magma cooled in part very slowly at great depths, in part somewhat more rapidly as a sheet buried under 8,000 feet of sediments, in part

as surface lava flows, and in part as glass fragments due to explosive eruptions. The time required for all these manifestations of activity from the one eruptive hearth extended from the Lower Huronian to the Cambrian or a somewhat later period of the Paleozoic.

Just why the nickel eruptive magma with its great masses of ore and its varied segregation products should occur near Sudbury and nowhere else in the vast Archaean region of northern Canada, there are no means of deciding; but prospectors familiar with the ore and its accompanying rock have looked for them far and wide, but in vain. Pyrrhotite has been found in considerable amounts in other places, but not in association with norite and with only a minute percentage of nickel.

The Sudbury nickel-bearing sheet is unique as far as America is concerned, and far surpasses in magnitude and economic importance the small areas of nickeliferous norite of Scandinavia and other parts of Europe. Its great marginal ore deposits may be compared in size and origin with the segregations of titaniferous magnetite connected with large gabbro areas, and the percentage of iron which they contain would make them valuable ores of iron but for the presence of sulphur.

THE COMPOSITION OF THE RED CLAY

F. W. CLARKE

In the volume upon *Deep Sea Deposits*, issued as one of the reports of the "Challenger" expedition, there are published twenty-five analyses of the "red clays."[1] This sediment is now recognized as the most extensive and important of all oceanic deposits, for it covers 51,500,000 square miles of the sea floor and is characteristic of the greatest depths. It is, therefore, obviously desirable to know its average composition as exactly as possible, and for that reason the following investigation was undertaken.

Of the analyses above mentioned 21 were by Brazier, 2 by Hornung, 1 by Klement, and 1 by Renard. They are, however, not strictly comparable, as a glance at the recorded data will show, nor are they, from the point of view of the modern analyst, so complete as they should be. For example, that ubiquitous element, titanium, was not determined in any of the analyses, for at the time they were made, its importance and relative abundance were not appreciated. Other substances, which are common in clays, were neglected for similar reasons, but their significance is now better understood, and improvements in analytical methods have made it easier to search for them. In Brazier's analyses the alkalies were not estimated, but were reported by the other analysts; an omission in the first group that was not due to oversight, but to the limitations of the purposes for which the work was done. The general nature of the red clay was well established, its great variability in composition was clearly shown, and its relations to other clays were made sufficiently plain to satisfy all ordinary requirements.

Of late years, however, it has become a matter of interest to determine the relative abundance and distribution of the chemical elements; and in an inquiry of that sort so notable a substance as the red clay could not well be neglected. A new and more elaborate

[1] *Deep Sea Deposits*, pp. 198, 201, 425–35.

analysis of it, therefore, seemed to be required, and to that end two methods of investigation were available. First, it was possible to make a number of individual analyses of separate samples, from which an average might be computed. Secondly, one composite sample could be analyzed, giving the desired information once for all. The first method, evidently, would have involved much labor, too much, indeed, to be justifiable. The second method would solve the problem equally well, but with greater ease and vastly less expenditure of time. The second, therefore, was chosen. Through the kindness of Sir John Murray, and his secretary, Mr. James Chumley, fifty-one samples of the red clay, from as many localities, and approximately equal in weight, were combined into a single sample, and that was analyzed by my associates in the laboratory of the United States Geological Survey.[1] The results of the composite analysis will be given presently.

The composite sample, as made up by Mr. Chumley, contained 35 samples from the dredgings of the Challenger expedition, 12 collected by the "Egeria," 2 by the "Waterwitch," and 2 by the "Penguin." Of these, 8 samples were collected in the Atlantic, 2 in the Indian Ocean, and 41 in the Pacific. The "Challenger" localities were stations Nos. 5, 9, 26, 27, 29, 160, 165, 181, 215, 221, 226, 228, 229, 230, 238, 240, 241, 244, 247, 251, 253, 254, 255, 256, 258, 259, 275, 277, 285, 286, 288, 294, 329, 330, and 353. These stations can be identified by reference to the published reports of the expedition.[2] The geographic range of the collection is evidently large enough to give a significant average, and the number of individual samples was also adequate. Twelve of the localities enumerated above are represented among the analyses already published in the volume on *Deep Sea Deposits* and are there indicated by their station numbers. The other localities furnished material hitherto unstudied chemically.

The new analysis of the clay was made upon the air-dried and unwashed sample. It, therefore, included adherent sea salts, and hygroscopic moisture, varying in these respects from the earlier

[1] The analytical methods employed were those prescribed by Hillebrand, in *U. S. G. S. Bulletin, No. 305*.

[2] A chart showing the position at which each sample was taken, was also furnished with the material sent for analysis.

analyses. The magnitude of these variations, however, was determined, and appears in the figures given below. The final data are as follows:

A. General analysis, by Mr. George Steiger.
B. Portion soluble in cold water, by Mr. George Steiger.
C. Special determinations, by Dr. W. F. Hillebrand.
D. Special determinations, on material concentrated from 150 grammes of clay, by Dr. E. C. Sullivan.

These last determinations were checked by blank experiments upon equal quantities of the reagents employed in the research.

TABLE I

	A.	B.	C.	D.
SiO_2	45.32	none	BaO.....0.16	CuO.....0.02
Al_2O_3	13.26	none	Cr_2O_3....0.011	PbO.....0.007
Fe_2O_3	7.20	none	V_2O_3.....0.035	ZnO.....0.004
FeO	0.70	none	MoO_3....trace	As_2O_3....0.0007
MgO	3.05	0.21		
CaO	6.82	0.19		
Na_2O	3.63	2.01		
K_2O	2.43			
H_2O at 106°	3.28	....		
H_2O above 106°	5.93	....		
TiO_2	0.82	....		
CO_2	3.91	....		
P_2O_5	0.25	....		
SO_3	0.48	0.39		
Cl	2.77	2.73		
F	none	....		
Cr_2O_3	0.01	....		
NiO, CoO	0.032	....		
MnO_2	1.01	....		
BaO	0.17	....		
SrO	0.046	....		
Li_2O	none	....		
V_2O_5	0.023	....		
	101.141	5.53		
Less O=Cl	0.62	0.62		
	100.521	4.91		

Zirconia and the rare earths were sought for by Dr. Hillebrand, but not found. Titanium, chromium, vanadium, barium, strontium, nickel, copper, lead, zinc, arsenic, and molybdenum were not reported in the "Challenger" analyses. Their widespread distribution in the igneous rocks is, however, well recognized. The absence of

lithium and fluorine is noteworthy. The unusually high proportion of manganese suggests the presence of disseminated or incipient manganese nodules, like that so admirably analyzed by Gibson.[1] In his work several of the rarer elements were determined; so that their existence in the oceanic sediments is no new discovery. The fact of their general distribution, however, remained to be proved.

In order to establish the true composition of the clay substance, some deductions must be made from the analysis as it is now stated. Hygroscopic water and soluble matter must be eliminated, and also the calcium carbonate which is represented by the CO_2. The composition of the aqueous extract, as given by Mr. Steiger's figures, is very near that of the sea salts. I have therefore taken Dittmar's analysis of sea salts as a standard, and subtracted their equivalent, as measured by the chlorine in the unleached clay, from the analysis of the latter. A slight excess of SO_3 remained, which I have also thrown out as representing gypsum. In short, from the general analysis I have withdrawn the water lost below 106°, the sea salts, the calcium carbonate, and a little gypsum, and recalculated the remainder to 100 per cent.

For comparison, I have combined the twenty-five analyses of the "Challenger" report into an average, from which similar subtractions, so far as they were needed, have been made. In this case only gypsum and calcium carbonate were rejectable. As for the combination, its value is not very great, because of the inequality shown by the individual analyses. Only in four of the latter were alkalies determined, and the mean of those four I have assumed to be representative of all. The ferrous oxide is even more doubtful, for it was only determined in one of Hornung's analyses, and neglected in the others. Still, as will be seen in the subjoined table, the comparison is not without significance, and even if it is not perfect, it is better than none at all.

The minor elements, not shown in the "Challenger" analyses, only sum up, altogether, to 1.36 per cent. Apart from these the comparison is satisfactory in some respects, not so in others. In silica, alumina, and water, the agreement is fairly good, but in iron,

[1] *Deep Sea Deposits*, pp. 422, 423.

the old analyses range much higher than the new. Possibly for the individual analyses, the reddest and therefore the most ferruginous samples were chosen for examination, as being presumably the most typical.

TABLE II

REDUCED ANALYSES

	Composite Analysis	Challenger Average
SiO_2	54.48	54.28
TiO_2	0.98	.....
Al_2O_3	15.94	16.41
Cr_2O_3	0.012	.....
Fe_2O_3	8.66	13.58
FeO	0.84	1.26
NiO, CoO	0.039	.....
MnO_2	1.21	1.62
MgO	3.31	1.76
CaO	1.96	0.74
SrO	0.056	.....
BaO	0.20	.....
K_2O	2.85	1.61
Na_2O	2.05	1.37
V_2O_3	0.035	.....
As_2O_3	0.001	.....
MoO_3	trace	.....
P_2O_5	0.30	0.35
CuO	0.024	.....
PbO	0.008	.....
ZnO	0.005	.....
H_2O	7.04	7.02
	100.000	100.00

On the proximate or mineralogical composition of the red clay, I have no important suggestions to offer. That problem was discussed at some length, in the "Challenger" report, on the basis of Brazier's analyses. In those analyses there was discrimination between the portion of the clay soluble in strong hydrochloric acid and the portion insoluble. In nearly every case the soluble ferric oxide was reported in excess of the insoluble; from which I am inclined to suspect that the iron of the clay is present, at least partially, in limonitic or glauconitic combination. The new, composite analysis shows a quantity of potash which suggests the presence of glauconite. The latter compound may well exist in a diffused

form, quite unlike its common granular variety, and therefore not so readily recognized. This is a mere suspicion, not entitled to much weight at present, but worth considering in future investigations. My specific problem has been to study the distribution of the chemical elements in nature, and to that end the composite analysis of the red clay is a step forward.

U. S. Geological Survey
Washington, D. C.
March 14, 1907

ADDENDUM

Since the foregoing pages were written I have received from Sir John Murray a composite of 52 "terrigenous" clays, dredged up from oceanic depths ranging from 140 to 2,120 fathoms. In the nomenclature of the "Challenger" expedition, 48 of the individual samples are classified as "blue muds," and 4 as "green muds." Twenty-three of the clays were collected by the "Challenger;" the others were brought in from voyages of the "Buccaneer," "Dart," "Egeria," and "Rambler." The range of collection, as in the case of the "red clay," was world-wide, and all of the great oceans are represented in the composite sample.

Molybdenum and zirconium were not detected. Nickel, cobalt, lead, zinc, and arsenic, which were reported in the red clay, were not looked for. Apart from these trivial omissions, the red and terrigenous clays are fairly comparable. The red clay is lower in silica and alumina, but higher in iron than the muds, and other minor differences appear. The high manganese of the red clay may be correlated with the abundance of manganese nodules in the greater oceanic depths. The results of analysis appear in the following table:

A. General analysis by Mr. Steiger.
B. Portion soluble in water.
C. Analysis reduced to standard form by rejecting soluble salts, calcium carbonate, and hygroscopic water, and recalculation of the remainder to 100 per cent.

TABLE III

	A.	B.	C.
SiO_2	46.64		57.09
TiO_2	1.04		1.27
Al_2O_3	14.08	.14	17.24
Cr_2O_3	.044		.05
Fe_2O_3	4.14		5.07
FeO	1.88		2.30
MnO	.10		.12
MgO	1.95	.18	2.17
CaO	7.20	.38	2.04
SrO	0.25		.03
BaO	.05		.06
K_2O	1.84		2.25
Na_2O	2.98	2.12	1.05
V_2O_3	.028		.03
P_2O_5	.17		.21
CO_2	4.05		....
SO_3	.32	.32	....
S	.11		.13
Cl	2.25	2.25	....
CuO	.016		.02
C	1.38		1.69
H_2O at $105°$	4.73		....
H_2O above $105°$	5.86		7.18
	100.883		100.00
Less $O = Cl$	.56		
	100.323		

June 27, 1907

THE GLACIATION OF THE UINTA MOUNTAINS[1]

WALLACE W. ATWOOD
The University of Chicago

OUTLINE

LOCATION AND GENERAL PHYSICAL FEATURES OF THE RANGE

The Uinta mountains are located in the northeastern portion of Utah. They consist of a single range of peaks extending in a general east-west direction. If the axis of the range were continued westward it would cross the Wasatch range nearly at right angles and enter the Bonneville basin a few miles south of Salt Lake City. Most of the range is included in the Coalville, Hayden Peak, Gilbert Peak, and Marsh Peak quadrangles of the Topographic Atlas published by the U. S. Geological Survey.

These mountains rise somewhat gradually above the plateau countries to the north and south. They reach their maximum elevation in the central portion of the range where the highest peaks are from 13,400 to 13,525 feet above the sea. The maximum elevation of the mountains above the surrounding country is about 7,000 feet. From the high central portion of the range the crest-line descends gently both to the east and to the west.

The width of the range is greatest in the central portion, where it measures, in a north-south line, fully 35 miles. To the east and west of the central portion the decrease in width is very notable. To the

[1] Published by permission of the director of the U. S. Geological Survey.

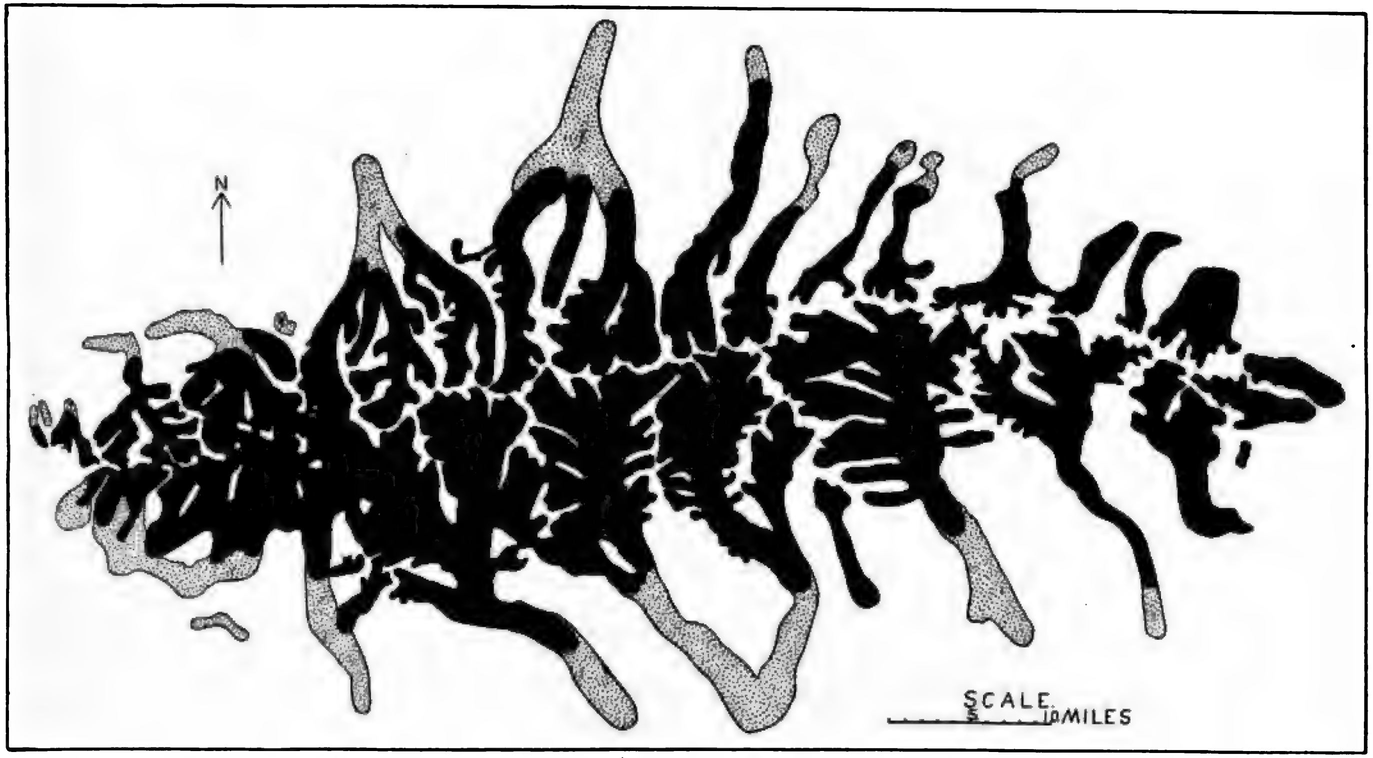


FIG. 1.—A map showing the extent and distribution of Pleistocene glaciers among the Uinta Mountains. Black represents areas covered by later epoch glaciers. Dotted portions represent additional areas covered by earlier epoch glaciers.

west the narrowing is symmetrical, and the terminus of the range is lobate in form, being sharply defined at the north and south by the valleys of the Weber and Provo rivers respectively. To the east the narrowing is not so pronounced or symmetrical, and, associated with the general flattening-out of the range in that direction, helps to account for the less conspicuous terminus at the east.

All the great canyons of the Uintas head near the crest of the range and descend approximately north or south. Since the axis of the range is nearer the north than the south margin, the north slope canyons are shorter than those on the south slope. All of the larger canyons have the characteristic U-shaped form due to glaciation. They have been well cleaned out by the ice in their upper portions, but in the middle and lower portions they contain heavy morainic deposits.

On the north slope, at the heads of the canyons, the basins vary from one to twelve square miles in area, while on the south slope they commonly include from twenty to thirty square miles (see Fig. 1). This difference, which had a very notable influence on the size of the glaciers, is consistent with the general structure of the range and will be discussed later.

THE EXTENT OF GLACIATION

At the period of maximum extension the ice covered by far the greater portion of the mountains west of Longitude 109 degrees, 40 minutes, and in a few cases extended beyond the mountains into the lower country to the north and south. The maximum extension of glaciation in an east-west direction was 82 miles, and in a north-south direction 42 miles. The total area covered by ice was something over 1,000 square miles. The portions of the range that rose above the ice near the crest-line were lofty peaks and narrow, rugged divides (see Figs. 2 and 3). Near the western end of the range in the region about Hayden Peak, Bald Mountain, Reids Peak, and Mount Watson, there was a great ice cap (see Fig. 1). Above this ice cap a few lofty summits (Fig. 2) rose as nunataks and helped to direct the movement of the ice into the canyons leading from this great center of accumulation. Six of the larger glaciers in the western portion of the range originated in this ice cap.

On the flanks of the range the areas not covered by ice were between the great canyons. These areas became broader and broader to the north and south, beginning as narrow ridges near the crest-line (Fig. 3), and broadening to plateau-like areas near the foothills. The portion of the range that rose above the snow-fields associated with the glacier must have been much less than that which rose above the ice. There is no way of determining how high the snow rested, but it is fair to assume that aside from a few lofty peaks

FIG. 2.—A portion of the Provo Basin. The passes have been glaciated but the peaks rose above the ice. The lake in the foreground is in a rock basin that was gouged out by the ice.

and narrow ridges the range appeared as a long white arch, rising about 7,000 feet above the country to the north and south, and suggestive, in form at least, of a partial reconstruction of the great Uinta anticline.

Most of the catchment areas in which glaciers were formed are 10,000 feet or more above the sea. A few favorably located basins between 9,000 and 10,000 feet furnished ice. The lower glacier basins are all near the western end of the range, where the snowfall was presumably greatest. Near the eastern margin of glaciation there are many basins above 9,000 feet in elevation that did not

contain ice. Three of the basins below 10,000 feet contained ice during the earlier epoch, but not during the later, indicating that, in general, a greater elevation was necessary for the formation of glaciers during the later than during the earlier epoch.

The glaciers extended southward and northward from the main crest-line, reaching their greatest lengths in the central portion of the area and decreasing in length both to the east and west, thus exhibiting a dimensional symmetry appropriate to the form of the range (see Fig. 1). The longest glacier was 27.5 miles in length; the shortest independent glacier was 1.5 miles long. During the earlier epoch there were thirty distinct glaciers. Most of these thirty glaciers may more properly be referred to as great systems, for in most cases they were formed by the union of from two to eight glaciers. During the later epoch, when the ice was not so extensive, fewer glaciers united, especially on the north slope, and therefore there was a larger number of distinct termini to the ice. The total number of independent glaciers during the later epoch was thirty-nine.

If the great systems of the earlier glaciers be subdivided and the tributary glaciers be counted as independent glaciers, there were:

8	glaciers	20 miles or over in length
3	"	15 to 20 miles in length
9	"	10 to 15 " " "
21	"	5 to 10 " " "
63	"	1 to 5 " " "

or a total of 104 glaciers over 1 mile in length.

COMPARISON OF THE GLACIATION OF THE NORTH AND SOUTH SLOPES

The lengths of the glaciers on the north and south slopes were, on the average, during the earlier epoch, about ten and sixteen miles, respectively. During the later epoch the lengths of the glaciers on the north and south slopes were about eight and ten miles, respectively. There were but two glaciers on the north slope that reached twenty miles in length, while on the south slope there were six that exceeded that length. The lower limits of glaciation on the two slopes are shown in the following table:

	Maximum Lower Limit during Earlier Epoch	Maximum Lower Limit during Later Epoch	Average Lower Limit during Earlier Epoch	Average Lower Limit during Later Epoch
North Slope...............	7,200	7,500	8,165	8,500
South Slope...............	6,600	7,250	7,661	8,112

The explanation of these striking differences seems to rest fundamentally on the general structural conditions in the range. The fact that the crest-line is nearer the north than the south margin of the mountains is of extreme importance. As a consequence, the north slope canyons are shorter than those on the south slope. They descend more quickly to elevations where ablation overcame the onward movement of the ice. Furthermore, the basins on the north slope are in a zone of inclined strata, while the south slope basins are located in the midst of essentially horizontal beds. These structural conditions account for the greater development of the catchment areas on the south slope than on the north slope. The widening of the basins, to be discussed more fully later, progressed more rapidly in the region of horizontal strata than where the beds are inclined. The larger catchment areas and the longer canyons are sufficient to explain the more extensive glaciation on the south slope. These factors seem to have outweighed in importance the greater protection from the rays of the sun on the north slope and the more favorable location for the lodgment of wind-blown snows on the north. The angle of the sun's rays must have caused more rapid melting on the south side, and the prevailing southwest wind must have carried much snow from the southern catchment areas and contributed to the northern fields, and yet, with the immense basins and long routes to low altitudes, the south slope glaciers far exceeded in magnitude those on the north slope.

GLACIAL EPOCHS

The chief facts about the extent of the ice during the different glacial epochs have been given. On the average, the earlier glaciers advanced from five to six miles farther down the canyons than did the later. In three basins there appears to have been ice during the earlier epoch and not during the later. A comparison of the lower

limits of glaciation during the two epochs is shown in the table already given.

The recognition of distinct glacial epochs among the mountains has associated with it some peculiar difficulties. When ice descended

FIG. 3.—One of the sharp divides in the basin region.

a canyon it was quite apt to obliterate all traces of any earlier ice advances through the same course. This was particularly true if the later ice advanced as far as any earlier ice. The chances of finding buried drift in these restricted courses of the ice are therefore much poorer than in the open country invaded by the continental

ice sheet. The mere fact that the area in which the data must be found, to prove distinct epochs for a given canyon, is so small, enhances the difficulties in the problem, and greatly reduces the chance of a demonstration. Where the later ice did not advance as far as the earlier, the case is more hopeful. In fact, in every case where distinct epochs have been determined in the western mountains, so far as the writer is aware, the earlier ice was more extensive than the later. In such cases the outer moraines have been subject to the processes of weathering and erosion for a longer period than the later or inner moraines. There may also be, associated with the two distinct systems of moraines, distinct outwash-deposits. These outwash-deposits must have a genetic relationship with the terminal moraines of the two epochs, and the older alluvium or valley-train may be expected to have suffered greater erosion than the younger. The composition of the glacial drift in a mountain canyon will be essentially the same each time that ice descends to a given point. But if the drift contains some easily weathered material, such as the coarsely crystalline rocks, the difference in the amount of weathering or disintegratio nof the bowlders may become- a strong argument. Among the Wasatch Mountains the older and the younger moraines may be easily distinguished by the difference in the amount of weathering. Among the Uintas this line of evidence is almost entirely wanting. The drift among the Uintas is composed largely of quartzite, in fact so largely that in most cases it is difficult to find a specimen of any other kind of rock in the drift. The drift of certain canyons is composed entirely of quartzite. Furthermore, the quartzite of the Uintas is so hard that the bowlders in preglacial conglomerates, derived largely from this formation, appear nearly as fresh as those in the youngest glacial deposits. The only difference that can be made out in the amount of weathering of the preglacial quartzite conglomerate and the quartzite moraines is that in the former there are more and larger bowlders that have been fractured, presumably by changes in temperature and by frost.

The determination of two epochs of glaciation among the Uintas rests chiefly upon these points:

1) There are two distinct systems of moraines in each of the main canyons.

2) The outer moraines are much more deeply eroded than the inner. Usually the outer terminal moraine has been entirely removed by erosion.

3) In some cases, where an older lateral moraine rests on a canyon slope above a younger moraine, the difference in the amount of erosion which each has suffered is very marked. Often there are valleys crossing the upper moraine which fail to cross the lower, and therefore appear as blocked valleys in drift above the lower moraines,

FIG. 4.—A glacial cirque in the western portion of the Uinta Mountains. The vertical walls and comparatively even floor are common characteristics of the catchment areas in the range.

just as blocked valleys in rock appear in the rock above the upper moraines.

4) Corresponding to the greater erosion in the outer moraines, there has been greater deposition. In many of the canyons, immense alluvial fans have been developed by side-streams that enter the main valleys at points below the terminal moraines of the later epoch and above the terminal moraine of the earlier epoch.

5) Depressions in the older drift have commonly been filled with alluvium. In this way, possible lakes or marshes have been obliterated. In the older moraines there are but few lakes and marshes while in the younger moraines lakes and marshes are common.

6) In three canyons there appears to have been ice only at a much earlier period than that of the later epoch.

7) In some cases two distinct valley trains have been determined, one being associated with the outer and the other with the inner moraines.

The alternative interpretation of the glacial deposits in the range is that the so-called younger moraines are recessional moraines deposited by the same ice that built up the outer older ridges. The marked differences in the age of these two series of moraines make this interpretation unsatisfactory. The time necessary for the removal of the outer terminal moraine, and the excavation of broad valleys in which the younger valley trains were deposited, must have been many times, perhaps ten, or twenty times, as long as the period that has elapsed since the final melting of the ice.

THE INFLUENCE OF TOPOGRAPHY UPON THE ICE

In an earlier paragraph it has been pointed out that the formation of the Uinta glaciers has been controlled by the size and elevation of the catchment areas. The case is equally clear that the movements of the ice were, in a large measure, dependent upon the topography of the range. At some places the divides were covered by ice, and yet in such places the underlying rock divides controlled the direction of ice movement, causing movement in opposite directions in a continuous ice mass. In the catchment areas the movement was in general pointed toward the canyon. From certain catchment areas the ice was forced to pass around isolated peaks and ridges that rose above the ice as nunataks; in some cases, to divide and move down different canyons on the same slope. The canyon ice was frequently forced by some projecting rock spur to swing to one side or the other. At constricted portions in the canyons the ice responded somewhat as rivers do and worked its way through the narrows, to deploy as soon as the walls of the canyon permitted. At several points the canyon ice was required to turn at right angles in order that it might move down valley.

THE INFLUENCE OF ICE ON THE TOPOGRAPHY

While the ice responded to topography, and in a large measure was controlled by the physical features of the range, yet at the same

time it was modifying the forms encountered, changing the shape of the great canyons, and building new forms.

Before the first Pleistocene snows fell on the Uinta Mountains, the heads of the great canyons may be fairly assumed to have been narrow V-shaped notches, reaching in most cases nearly to the crest-line of the range. The first ice was formed in these narrow canyon heads, and the earliest movement must have been distinctly down canyon. As the ice at the heads of the canyons increased in thickness, there came to be a notable movement down the sides of the gorge, concentrating the ice in the canyon and causing further movement down stream. With the movement of the ice on the side slopes, these miniature catchment basins were both widened and lengthened. About the margin of the ice fields weathering and ice plucking was in progress. Such work has been pointed out by Johnson[1] to be going on today at the base of the Bergschrund. In this way the catchment areas were increased in size and changed into cirque-like forms (see Fig. 4). Such work has been described by Penck[2] as follows:

> Glaciers not only exercise a sapping action along their sides, but also at their very heads, if they are here overlooked by rock cliffs. There is always a marginal crevasse, called in German, Randspalte or Bergschrund, which separates the moving ice from the rocks which overlook it. The material loosened here by weathering falls down from the rock walls into this crevasse and arrives at the bottom of the névé, where it is pushed forward by the mass grinding the bottom of the glacier. By this, not only the formation of screes around the glacier is hindered, but also the surrounding cliffs are constantly attacked, for the erosive action begins just at their foot and saps them. Glaciers therefore, which are formed on slopes in broadly open valley basins, surround themselves finally by cliffs, which are pushed backward much as are the cliffs around the gathering basin of a torrent.

Just south of the main crest-line, weathering and the plucking work of the ice went on under the most favorable conditions. There the strata are essentially horizontal and sufficiently variable in hardness to favor rapid disintegration. The giving-way of the softer beds left the overhanging harder strata exposed. Cliff and talus slopes developed, and the ice, working sideward and headward, or in general

[1] *Journal of Geology*, Vol. XII, p. 573.

[2] *Journal of Geology*, Vol. XIII (1905), p. 15.

outward, around the margin of the ice field, would work these steps or benches farther and farther back. Sometimes a very resistant layer of quartzite served for several square miles as a base to which the quarrying work of the ice went on. Then another resistant layer, 10, 20, or even 200 to 300 feet higher, would serve as the floor of the quarry. The work therefore went on in something of the fashion in which men widen and deepen quarries in similar formations. Many abandoned benches remain today about the margins of the great catchment areas.

Corresponding to the widening of the basins, there was a narrowing of the divides between the heads of the canyons and of the main crest of the range. Some of the divides (see Fig. 3) were so reduced that it is dangerous to try to walk along them. Others were surmounted and greatly reduced by the ice. The main crest-line was sharpened, and the peaks were given greater prominence.

In the canyons the great change was the development of the broad U-shaped troughs. The preglacial forms were largely obliterated. The canyons were widened and deepened. In this process many tributaries were left as hanging valleys with their lower ends several hundred feet above the main stream. Preglacial erosion lines, and asperities common to the slopes of unglaciated canyons, were commonly rubbed off as far up as the ice rested.

In the bottom of the gorges, on the canyon walls, and in the basins, the glaciers built up new topographic forms. The terminal moraines have an average depth of about 400 feet. In one instance, however, it is clear that there is at least 1,000 feet of morainic material at the mouth of the canyon. These moraines are often ridgelike in form but where the glaciers pushed out on the lowlands bordering the mountain range, they have a hummocky topography similar to the terminal moraines left by the continental ice sheet of the interior region. At intervals, up stream from the terminal moraine it is customary to find other morainic ridges or belts crossing the valley in the manner of recessional moraines. Above these recessional moraines lakes are sometimes located, but more commonly swamps, which are being drained as the main streams lower their courses through the morainic dams. The lateral moraines are lodged as ridgelike forms on the valley slopes. The crest-lines of these lateral ridges increase in

elevation above the stream bed for several miles up the canyon from the terminal moraines, until, near the basin region, the canyon walls become too steep to permit the lodgment of loose débris. The elevation of the lateral moraines indicates that the ice in many of the canyons was but 600 or 700 feet thick, but where the larger glaciers existed the ice was from 1,500 to 2,000 feet thick, and in one case 2,500 feet thick. The extensive terraces extending down stream from the terminal moraines are remnants of valley trains deposited by the waters associated with the glaciers.

POLISHED AND STRIATED SURFACES

The polished and striated surfaces of bed rock are restricted almost exclusively to the basin regions. In the areas where the drift is scarce, striae, grooves, polishings, and *roches moutonnées* are common. Square miles of bed rock are exposed in the higher portions of the range, where the signs of ice action are beautifully shown. In many of the passes in the main crest-line, glaciated surfaces appear. Striae have been found as high on some of the peaks as any other signs of ice action, and about the marginal portions of the basin regions ice action is often recorded both in glaciated surfaces and ice-gouged basins in the hard quartzite rock. A few striated rock surfaces have been found deep in the canyons and on benches or shoulders on canyon walls.

INFLUENCE OF GLACIATION ON DRAINAGE

The hundreds of glacial lakes and marshes indicate, especially in the basin region of the range, how generally the drainage has been modified by the ice. Scarcely a basin exists where waters are not yet ponded by the morainic deposits or retained in rock basins gouged out by the ice. In a few cases tributary streams in unglaciated valleys have been ponded by lateral moraines of a main canyon. Terminal and recessional moraines have in some canyons blocked the courses of the main streams and caused the formation of chains of lakes. At the close of the glacial period such chains were much more common than they are today, but in their places are chains of meadows, separated from each other, as the former lakes were, by morainic ridges. There are now more than 550 glacial lakes among

the mountains. In the catchment basin of Provo Canyon there are at least forty-three lakes, and from the summit of Bald Mountain overlooking the area formerly covered by the ice cap seventy lakes may be seen. In a few cases streams are today partially ponded by morainic dams. In these cases the drift is not sufficiently compact to hold the waters until they rise and overflow, but, seeping through the loose deposits, the waters issue a short distance down the canyon as large springs. The glacial lakes vary in their longer diameters from a few rods to one mile and a half. Most of them, however, are less than half a square mile in extent.

The hanging valleys may also be mentioned in this connection, for they are instances of marked changes in drainage. In this way scores of tributary streams have been thrown out of adjustment with their mains. Falls and rapids have been caused which centuries of work may not remove from the stream courses.

POSTGLACIAL WORK

Since the ice last left the Uinta Mountains, the work of weathering and erosion has been, with the exception of certain inner gorges on the south slope, trivial and insignificant. The moraine material of the later epoch is but little disintegrated, and most of the streams are yet engaged in cleaning away the glacial débris from their courses. Near the summits changes in temperature, frost, gravity, and moving névé, have so combined as to produce extensive talus accumulations about the margins of the basins. The inner rock gorges in the main south slope canyons are the most striking postglacial features in the range. On the average they are fifty to eighty feet deep and from five to six miles long. They are limited to the upper portions of the canyons, and do not appear to be due to a general rejuvenation of the streams. They are in those portions of the canyons where the deepening by the ice was greatest, and therefore where the stream bed would be expected to be relatively low, and yet these inner rock gorges are distinctly below the level of ice wear and are not glaciated. The favorite hypothesis for the explanation of these gorges has been a slight postglacial uplift along an east-west line about ten miles south of the axis of the range.

GLACIATION AND IRRIGATION

The present streams from the Uinta Mountains, if under control, would furnish enough water to irrigate hundreds of square miles in the lower country. If the glacial lakes were connected directly with the streams and used as reservoirs, the irrigating capacity of the streams would be immensely increased. Usually a relatively inexpensive dam would control the waters of these natural reservoirs. In most cases the lake waters could be easily increased a few feet in depth, and often spread over many additional acres of land. In a few cases simple efforts have been made to control the waters in such lakes. China Lake, in the east fork of Smith's Fork, now serves as a reservoir. At the south end of Lake Washington in the Provo Basin a dam was built which, if effective, would have raised the waters in the lake a few feet and reserved a large supply of water for the latter part of the growing season. The dam is now broken, and the outlet of the lake is being gradually lowered by the outflowing waters. In many cases outlets of former glacial lakes could be closed and new reservoirs made. Often the younger terminal moraines in the canyons have but narrow notches cut through them. If these postglacial notches were closed, there would be extensive reservoirs in the lower portions of the canyons.

Most of the irrigable land south of the mountains is at present owned by the Ute Indians. The Indians carry on some agricultural work, but only near the streams, where the land is very easily watered. The country north of the range is inhabited by ranchmen, who find it more and more necessary each year to raise fodder for their stock. The land is being rapidly taken up and fenced off for private ranges. In this country irrigation is practiced somewhat extensively, and yet little or nothing has been done to control the waters in the basin region or to develop new reservoirs lower down in the canyons. Each year the streams are lowering the outlets of the lakes and both widening and deepening the cuts through the moraines in the canyons, and therefore the amount of work necessary to get control of the water supply in the range steadily increases.

NOTES ON THE PENNSYLVANIAN FORMATIONS IN THE RIO GRANDE VALLEY, NEW MEXICO[1]

C. H. GORDON
Knoxville, Tenn.

INTRODUCTION

A number of papers have appeared in recent years concerning the Carboniferous formations in the Rio Grande Valley. As the observations therein recorded were almost wholly of a reconnaissance nature, it is not to be wondered at that more or less divergence is manifest in the views of the different writers concerning the stratigraphy of the region. This paper is based on observations made during a year's residence at Socorro, together with several months' field-work in connection with the investigation of the mines and mining districts of New Mexico under the direction of Mr. Waldemar Lindgren of the U. S. Geological Survey. The results of that investigation are to appear in a forthcoming bulletin of the Survey. In the present paper it is the chief purpose of the author to present a brief description of the rocks in the Rio Grande Valley which represent the lower part of the "Coal Measures" of adjoining regions, and to discuss their stratigraphical relations and the nomenclature connected with them. For these beds in the Survey paper above mentioned the name Magdalena has been adopted as a group term.

[1] Published by permission of the Director, U. S. Geological Survey.

GENERAL RELATIONS OF THE PENNSYLVANIAN ROCKS IN THE REGION

In the Rio Grande Valley the Upper Carboniferous or Pennsylvanian series is represented by a succession of limestone, shale, and

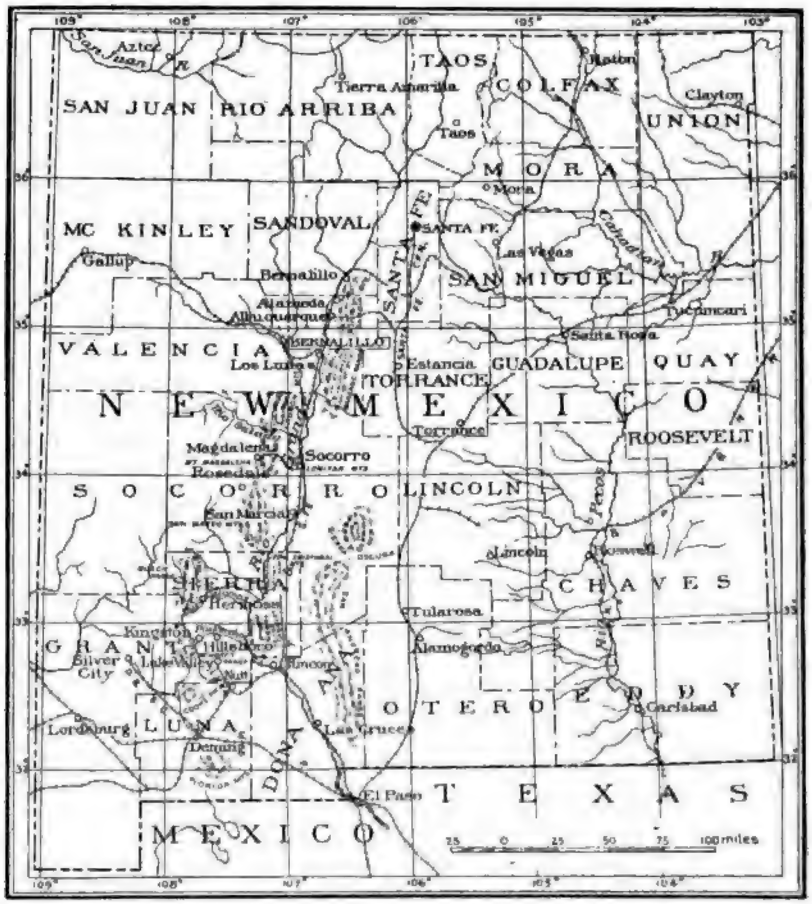
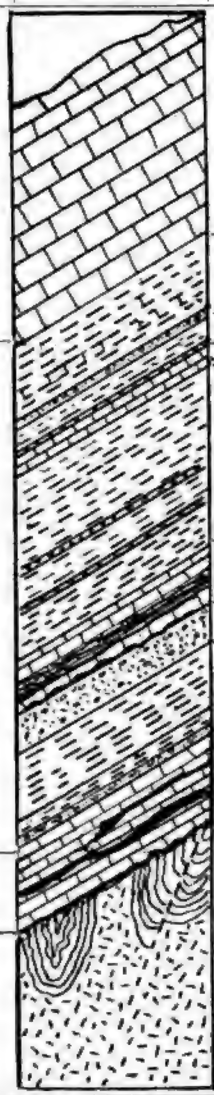


FIG. 1

sandstone formations, having an aggregate thickness of from 3,000 to 5,000 feet. These may be separated into two main divisions or groups, to the lower of which the name Magdalena is here applied, from the Magdalena Mountains, where they are well exposed, while the upper division comprises the formations, chiefly sandstone, to

MAGDALENA SECTION



System	Series	Gr.	Form	Column	Thick	Character Rocks
Carboniferous	Pennsylvanian	Magdalena	Madera		300 to 500	Blue compact limestone for the most part thick-bedded: Some shales.
			Sandia		.15 6 30 410	Shales, limestones and conglomeratic sandstones or quartzites.
					75	Compact earthy limestone and shales.
					40	White conglomeratic quartzite.
					125 40	Shales and quartzites with conglomerate at base.
					125	Subcrystalline limestone with compact 5-foot layer (Silver Pipe) near middle. } Ore Beds
	Miss.	Kelly				
Pre-Cambrian						Greenstone schists and granite.

which Herrick[1] applied the term Manzano, from the Mountains of that name northeast of Socorro, in Valencia County, together with the limestones found overlying the sandstones in regions south of Bernalillo County, which Lee[2] has shown to belong to the series.

Southward in Sierra County, where the Pennsylvanian and Lake Valley (Lower Carboniferous) formations occur together, the relations are those of apparent conformity. The Lower Carboniferous formations thin out northward in Socorro County and are not known to occur north of the Ladrone Mountains. In the Magdalena Mountains the basal beds of the Pennsylvanian are conglomerates and shales, which rest with apparent conformity upon the Kelly (Lower Carboniferous) limestone. Northward in Bernalillo County the Pennsylvanian rests unconformably upon granites and other rocks of supposed pre-Cambrian age. A well-marked unconformity occurs also at the base of the Manzano division east of Socorro, as shown by Herrick,[3] who first recognized it and who states that this is evidently an unconformity by overlap. Lee[4] has shown that the Manzano beds are separated from overlying formations by great erosional unconformity. The twofold division of the Pennsylvanian formations is sustained therefore both by faunal distinctions, according to Dr. George H. Girty,[5] and by relations of unconformity as well. The faunal studies thus far made do not show any marked change in the life represented within each division, and the subdivisions are based entirely on lithological distinctions.

THE MAGDALENA GROUP

In general the Magdalena group may be said to be characterized by the predominance of limestone, while, on the other hand, sandstones constitute the most prominent feature of the Manzano group. In Sierra County the Magdalena group consists for the most part of massively bedded blue and gray limestone, interstratified with which

[1] C. L. Herrick, *Journal of Geology*, Vol. VIII, p. 115, 1900; *Am. Geol.*, Vol. XXV, p. 337, 1900; *Bull. Univ. New Mex.*, Vol. II, Fascicle No. 3, p. 4, 1900; *Jour. Geol.*, Vol. XII, p. 244, 1904.

[2] W. T. Lee, *ibid.*, Vol. XV, pp. 53, 54, 1907.

[3] *Jour. Geol.*, Vol. XII, p. 244.

[4] *Ibid.*, Vol. XV, p. 54.

[5] *Ibid.*, p. 54.

are thin-bedded limestone and dark-blue shale. Occasionally, a thin bed of sandstone may be seen. At Kingston, on the east slope of the Black Range, the basal beds consist of about 300 feet of dark-blue and gray limestone in thick beds with thin shale partings. The upper portion has about the same thickness and consists chiefly of blue and drab shale interstratified with several limestone formations varying from fifteen to twenty feet in thickness. Resting unconformably upon the shale formation are the red sandstones and shales of the Manzano group.

At Palomas Camp, in the Black Range, twenty-five miles north and a little west of Hillsboro, the county seat of Sierra County, and two miles east of Hermosa, the Rio Palomas has cut a gorge 1,000 feet deep through the sedimentary formations. The walls of the canyon are nearly vertical and consist almost wholly of blue and gray limestone of the Magdalena group. The lower half of the escarpment consists of limestone and shale in about equal development, while the upper portion is made up of hard, massively bedded gray limestone. About half-way up the cliff a few thin beds of quartzite appear interstratified with limestone. The overlying Red Beds of the Manzano group, together with some of the upper beds of limestone, have been removed by erosion at this point, but the red sandstones occur in considerable development a short distance to the northwest.

In the Caballos Mountains, about twenty-five miles east of Hillsboro, the group is represented chiefly by limestones, with some shale beds in the basal part, as at Hermosa, but we are unable to give details of the formation at this locality. They were observed resting with apparent conformity upon other limestones considered to be of Lower Carboniferous age, while below these, and separated from them by a thin bed of the Percha shale (Devonian), is a heavy development of limestone (900 ft.) belonging to the Mimbres formation (Ordovician).

The data at hand concerning these formations in Sierra County are insufficient to warrant an attempt to subdivide the group. The character of the beds at Hermosa suggests the twofold division observed farther north, and in connection with the character of the formations in adjoining districts indicates a gradual transition in sedimentation from shallow-water conditions at the north to deeper waters toward the south. With the progress of time the entire region apparently

assumed conditions of deep and clear waters wherein were deposited the extensive limestone beds which constitute the upper part of the division (the Madera limestone).

Northward in Socorro, Valencia, and Bernalillo Counties the Magdalena division comprises from 1,000 to 1,300 feet of sediments, the character of which in their typical locality will be seen from the section on p. 807.

The rocks of this division contain a characteristic Pennsylvanian fauna, which shows no essential variation from the base to the top of the series, but on lithological grounds they are readily separable into two formations, to the lower of which Herrick[1] gave the name Sandia Beds (or series), from the Sandia Mountains, where they were first studied, while the upper is known as the Madera limestone.[2]

Sandia beds.—In Socorro County the Sandia formation consists of alternating beds of blue and black clay shale, compact earthy limestone, and conglomerate, vitreous sandstone or quartzite, the shale and limestone predominating. In places, the shales are highly carbonaceous and sometimes show traces of coal, but thus far no coal beds of importance have been discovered in this formation. The sandstones are usually hard, with a vitreous fracture, and present the characteristic appearance of quartzites. The beds are often conglomeratic, the included pebbles consisting for the most part of pure-white quartz. The basal beds of the series in the Magdalenas, comprising a thickness of ten to fifteen feet, consist of a moderately coarse conglomerate interbedded with dark shale. While these beds rest apparently conformably upon the limestones below, the relations are undoubtedly those of unconformity. About 125 feet above the base of the series is a formation of coarse white quartzite or conglomerate in massive ledges separated by thin beds of shale. Some of the quartzite beds are filled with pebbles. Overlying this is a limestone formation eighty to ninety feet thick, in which appear some thin beds of shale and quartzite. At the base of this limestone formation is a thick-bedded dark-blue subcrystalline limestone six

[1] C. L. Herrick, *Jour. Geol.*, Vol. VIII, p. 115, 1900; *Am. Geol.*, Vol. XXV, p. 235, 1900; *Am. Geol.*, Vol. XXXIII, p. 310, 1904.

[2] C. R. Keyes, "Water-Supply Paper No. 123," *U. S. Geological Survey Report*, 1904.

feet thick overlaid by about twenty-five feet of shale and thin limestone above which occurs two feet of quartzite followed upward by fifty feet of compact bluish earthy limestone. It is at the contact of the shale and limestone formation with the conglomerate below that the "upper" or "surface" ore deposits occur at Kelly.

These Sandia beds are well exposed on the east slope of Mount Socorro, and northward in the Limitar Mountains. They also appear on the east side of the river opposite Socorro and elsewhere.[1] Southward, as stated above, there is a marked decrease in the porportion of sand and clay beds accompanied by an increase in calcareous sediments. The shaley beds which constitute the lower part of the escarpment near Hermosa are evidently the equivalent of the Sandia beds as represented in Socorro County, but farther south the distinction between the upper (Madera) and lower (Sandia) divisions of the Magdalena is not recognizable.

The thickness of the sediments referred to this division varies from 500 to 700 feet.

Madera limestone.—Overlying the Sandia beds in Socorro and Bernalillo counties is a dark-blue limestone, for the most part in thick beds alternating with other thin shaley beds and blue shale. The limestone contains many fossils of the same type as those found in the Sandia beds below, but owing to the extreme hardness of the rock specimens are difficult to obtain.

These limestones constitute the top of the ridge above Kelly, where they have a thickness of about 300 to 500 feet, having been partly removed by erosion. On Mount Socorro they reach a thickness of about 700 feet, while good exposures of the beds appear also in the Limitar Mountains. The Madera beds constitute the great limestone plate along the back slope of the Sandia Mountains, and upon this limestone plateau is located the little Mexican town of La Madera, from which the formation is named.[2]

Herrick[3] has described the lower part of the formation in the Sandias as consisting of dark limestone, while the upper beds are of massive, gray siliceous lime with an intervening sandstone or con-

[1] C. L. Herrick, *Jour. Geol.*, Vol. VIII, pp. 114, 115, 1900.

[2] C. L. Herrick, *Bull. Univ. of New Mex.*, Vol. I, p. 104, 1899.

[3] C. L. Herrick, *Jour. Geol.*, Vol. VIII, pp. 114, 115, 1900.

glomerate of inconstant thickness (40 feet at the maximum) which he calls the Coyote sandstone, from the canyon of that name in the south end of the Sandia Mountains.

THE MANZANO GROUP

Above the Madera limestone and resting unconformably upon it in the Rio Grande region, is a series of red and pink sandstones and shales with deposits of gypsum capped by a prominent formation of limestone. These red sandstones and shales constitute in part the beds usually regarded as the equivalent of the Kansan Red Beds called Permian, while some of the upper beds were thought by Herrick to be Jura-Trias in age.

The writer's observations of these formations, though limited, led him to regard them as belonging to the Pennsylvanian series, a conclusion fully established by the more detailed studies of W. T. Lee,[1] of the U. S. Geological Survey. The series of variegated sandstone, shale, and gypsiferous beds was described by Herrick[2] from the Manzano Mountains, northeast of Socorro, in 1900, and by him named the Manzano series. In the southern part of the region a limestone formation several hundred feet in thickness overlies the red beds, and from it Lee obtained a large collection of fossils which are distinctly allied to those obtained from the red series, the whole, as stated by Dr. Girty,[3] being distinctly Pennsylvanian, though markedly differing from the fauna of the lower, or Magdalena, group. Northward in Bernalillo County the upper limestone member is absent, and variegated sandstone and shale beds, similar to those of the Morrison formation, rest upon the pink sandstones, with an intervening erosion unconformity.[4] Lee considers the Manzano group lithologically separable into three divisions, the lowermost of which consists principally of dark red sandstones interstratified with red sandy shales and some thin beds of bluish-drab earthy limestones. At the base of the

[1] *Jour. Geol.*, Vol. XV, pp. 52–58, 1907.

[2] *Jour Geol.*, Vol. VIII, pp. 115, 116, 1900; *Bull. Univ. New Mex.*, Vol. II, Pt. 1, Fascicle No. 3, p. 4, 1900.

[3] Quoted by Lee, *Jour. Geol.*, Vol. XV, p. 54, 1907.

[4] The description and classification of the Manzano beds is to appear in a forthcoming publication by Messrs. Lee and Girty.

formation is a limestone conglomerate the pebbles of which were derived from the underlying Madera beds. Above this, as seen in the hills east of Socorro, is a coarse red granitic quartzite conglomerate. The thickness of the red sandstone division varies from 400 to 800 feet. Overlying these beds occur alternating strata of yellow, pink, and white sandstones and shales with lenses of gypsum and a subordinate amount of limestone. In places the gypsum is massive and reaches a thickness of 140 feet. The total thickness of this formation ranges from 500 to 1,000 feet. The uppermost division of the Manzano group consists for the most part of gray limestone in which an abundant fauna occurs. These beds are well developed in the mountains east of Socorro and southward in the San Andreas Mountains east of Engle, but were not observed on the west side of the Rio Grande. According to Lee this limestone is not present in the Sandia Mountains. The total thickness of the formation is from 300 to 500 feet. Several miles northeast of Socorro, and in plain sight from this place, are a number of minor elevations called the Coyote Buttes. At this locality the Manzano beds are well exposed in the west face of the hills, the strata dipping sharply to the northeast. The red sandstones of the lower division occur on the west of the Magdalena Range south of Kelly and along the east side of the Black Range from Fairview south to Kingston. The overlying beds were not observed in the Black Range region.

Heretofore these red-sandstone formations have been at times confounded with the Red Beds supposedly of Permian and Triassic age, but according to Dr. Girty,[1] who has made a study of the fossils collected from them by Mr. Willis T. Lee, of the Survey, they are undoubtedly Upper Carboniferous and correspond in their relations to the upper part of Richardson's Hueco formation in Texas and the Aubrey in the Grand Canyon region.

In the Mount Taylor region, sixty miles west of the Rio Grande, there are 1,200 feet of Upper Carboniferous red and yellow sandstones, according to Dutton, who identified them with the Aubrey and used that name for them.

Nomenclature.—While there have been published a great many papers relating to the region under consideration, very little detailed

[1] Personal communication.

work has been done, and the names applied to different formations have been in some cases not at all defined, while in others the descriptions can be interpreted only with the greatest difficulty. A few names, however, are well established. Herrick[1] applied the name Sandia beds, or Sandia series, to the alternation of shale, limestone, and sandstone which constitute the lower half of the Magdalena division in Socorro and Bernalillo counties in 1900, and his description is such that no difficulty is encountered in the application of this term. At the base of the formations east of Socorro is a bed of clay containing Carboniferous plants to which Herrick gave the name Incarnacion Fire Clay, but he expressly states, "There would seem to be no reason for separating the fire clay from the Sandia formation, it being but a local variation."[2]

The limestone formation overlying the Sandia beds he appears to have left unnamed, but to the bed of sandstone which occurs near the middle of the formation in the vicinity of Coyote Springs, Bernalillo County, he gave the name Coyote sandstone.[3]

The same author applied the name Manzano[4] to the series of red sandstone and other beds which overlie the rocks of the Magdalena division in the Manzano Mountains and adjacent regions. His description of these beds does not make it altogether clear whether he meant to apply the name to the lower red sandstone alone or to the whole series, including the gypsiferous beds, the chocolate-colored sandstones, and their accompanying shales and earthy limestones. It would seem, however, that the latter was his intention. He does not seem to have included under this name the limestone overlying the pink and yellow sandstones, which, as shown by Lee,[5] belong in the series.

In a recent paper, C. R. Keyes[6] presents a classification of the Carboniferous rocks of New Mexico in which several new names appear, but without adequate definition. The shale bed at the base of the Sandia formation he separates, giving it the name Alamito, and

1 C. L. Herrick, *Jour. Geol.*, Vol. VIII, p. 115, 1900; *Am. Geol.*, Vol. XXV, p. 235, 1900; *ibid.*, Vol. XII, pp. 237–251, 1904.

2 *Jour. Geol.*, Vol. XII, p. 242, 1904. 3 *Jour. Geol.*, Vol. VIII, p. 115, 1900.

4 *Loc. cit.* 5 W. T. Lee, *Jour. Geol.*, Vol. XV, pp. 53, 54, 1907.

6 C. R. Keyes, *Jour. Geol.*, Vol. XIV, pp. 147–54, 1906.

makes it the equivalent of a series to which the name Ladronesian is applied. No evidence in support of this separation is given, and Herrick specifically states that none exists. For the remaining part of the Magdalena division Keyes uses the term Manzanan. Even a cursory reading of Herrick's description is sufficient to show that these are not the beds for which the name Manzano was originally proposed. For subdivisions of the rocks included under his term Manzanan, Keyes uses, in addition to Herrick's terms Sandia beds and Coyote sandstone, the name Montosa for the limestone below the Coyote sandstone, and Mosca for that above. No evidence is given that will warrant the establishment of these formation names. Our own observations lead us to conclude the Coyote sandstone to be of local development and the subdivision of the Madera formation to be unsupported by the evidence thus far available.

Overlying his so-called Manzanan, the same author[1] notes a limestone formation which he calls Maderan. Evidently he regards this as the same formation which in an earlier paper he says is, in the Sandia Mountains, called the Madera limestone, and adds that it forms by far the most important portion of the Carboniferous in all the mountain ranges mentioned. From Herrick's description of the geology of the Sandia Mountains, which is corroborated by the studies of W. T. Lee,[2] of the U. S. Geological Survey, it is clear that the great limestone formation of the Sandias is the limestone which constitutes the upper half of our Magdalena division and comprises the formations to which in the same table[3] Keyes gives the names Montosa and Mosca, with the included Coyote sandstone. The discrepancies in this case are apparently due to confounding the Madera limestone in some places with the limestones at the top of the Manzano group. Inasmuch as the name Madera very appropriately applies to the limestone overlying the Sandia beds in the Sandia Mountains, it may well be retained for the upper formation of the Magdalena division.

In the following table is presented, in convenient form for comparison, the classifications of the Pennsylvanian rocks in the Rio Grande region by the different authors mentioned.

[1] "Water-Supply Paper, No. 123," *U. S. Geol. Survey Report*, p. 22, 1905.

[2] Personal communication.

[3] *Jour. Geol.*, Vol. XIV, p. 154, 1906.

Gordon and Lee, 1907: Series	Group	Formation	Character of Rocks	Herrick, 1900		Keyes: 1904		1905		1906		
Pennsylvanian	Manzano		Unconformity Limestone. 300–500 ft.	Limestone	Jura-Trias	Cimarronian	Triassic	Red beds	Permo-Carboniferous	Moencopie shales	Cimarronian	Permian
			Pink or vermilion and yellow sandstones, shales and earthy limestones, and gypsum beds. 500–1,000 ft.	Manzano						Sandstone shales		
			Red sandstones and conglomerates with some earthy limestones. 400–800 ft.		Permian	Bernalillo shales		?		Capitan L. S. Eddy sandstone	Guadaloupan*	
	Magdalena (Gordon, 1907)	Madera	Unconformity Limestones with some shales and sandstones. 600–1,000 ft.	Limestone	Permo-Carboniferous	Madera limestone	Carboniferous	Madera limestone	Pennsylvanian	Maderan limestone	Maderan ("Hueco in part")	
				Coyote S. S. Limestone	Coal measures					Mosca limestone	Manzanan	Pennsylvanian
										Coyote S. S.		
		Sandia	Alternating shales, limestones, and sandstones. Toward south nearly all limestones. 500–600 ft.	Sandia beds (or series)		Sandia limestone		Sandia quartzite		Montosa limestone		
										Sandia shales		
		Unconformity	Unconformity							Alamito shales	Ladronesian	

* Not known to be represented in Rio Grande region.—Gordon.

EDITORIAL

RESOLVED that the Mississippi Valley Association of State Geologists expresses its belief in the desirability of a thorough reconsideration of the principles which should govern the nomenclature of geology, and its willingness to co-operate in any movement for the bettering of present conditions.

AND RESOLVED that copies of this resolution be sent to the secretary of the Geological Society of America, be presented to the conference of geologists now in session in Washington, and to Director Smith of the U. S. Geological Survey.

This is an action most heartily to be commended. We note with peculiar pleasure that the association desires *a thorough reconsideration of principles*, not a mere temporizing agreement for putting into more common and oppressive use current methods, some of which are good, some indifferent, and some bad. A special nomenclature is a grave burden to a science at best, but when it becomes positively bad, the affliction is grievous indeed. Geology does not suffer from this so much as the biological and mineralogical sciences, but it necessarily participates in their afflictions and has some special and quite unnecessary ones of its own. It is probably safe to say that several times as many people as are now interested in our science would be among its enthusiastic promoters, if its great truths had been habitually clothed in the plainest available terms in the literature of the past century. The history of the earth and of its inhabitants, the processes of its evolution, and the facts of its structure are inherently interesting, and if the story were so told that it could be read easily and intelligibly, it would give both pleasure and profit; but the current of the reader's enjoyment is so often needlessly checked by unintelligible terms, that he soon becomes weary and lays the annoying text aside for something less trammeled by pedantic toggery. This is not solely a layman's affliction. Geological readers of no mean literary and scientific attainments are all too frequently caught and held by the briars and brambles of our crudely technicalized literature. The fundamental sin is the offspring of the vanity of scholasticism. Could anything better characterize the typical scholasticus than our practice of using "syncline" for bent strata that outcrop divergently,

and "anticline" for those that outcrop convergently? The terms do not even become intelligible when the reader is told that they are "from the Greek . . . . , meaning . . . . ;" he must learn and *constantly remember* that there is a suppressed "downward" to be read after each of these terms. The "downward" is consistently suppressed, for it is just as plebeian as sag or arch, or any of the vulgar English equivalents which might have been used to tell the whole story in the first place. But the folly does not all lie in the vanities of classical erudition. It is just as bad to make "heave" mean a horizontal movement as to make "syncline" mean bent beds that diverge as they outcrop. The literature of science is full of phrases wrested from their current meanings and forced into special senses, which special and forced senses *must always be remembered*, if the reader would know what is meant. "Viscous" was a good word before it was criminalized. Starting with a liquid like molasses, we could once say that, as it was boiled, it became more and more viscous up to a maximum viscosity, beyond which, either by further boiling or by cooling, it became less viscous and more solid until it came to be distinctively rigid and brittle, a state which common people never thought of calling viscous. So, on the other hand, starting with glass, a very brittle solid, we could say that on heating it became gradually more and more viscous up to a maximum viscosity, beyond which it became more and more liquid and less and less viscous. Viscous then meant a certain peculiar intermediate state between the liquid and the solid, with a maximum viscosity midway, a phenomenon so common and distinctive as to need an appropriate term. Now, however, by a misguided technicalization the term is scarcely less than Mephistophelian in its competency to beguile the unwary.

But it was not this phase of the subject, we surmise, that the association had in mind. Its members are probably ready to accept the sins of the past, if they may avoid the afflictions of the future. They probably had in mind the "pernicious activity" displayed in certain quarters in putting new names in the place of old ones, sometimes better, often worse, under pretext of correlation, etc., without a sufficient basis for so doing either in the thorough study of the formations, or of the merits of the names, or of the principles involved, and without due regard to the economies of the profession or the conven-

ience of the public. The cheapest device for making the largest show of quasi-results in technical garb with the least investment of scientific capital known to our profession is found in giving new names to known formations, because of some real or imagined objection to the names in use, or because some new division may be thought to be better, or because some arbitrary "rule" is violated, or because of a premature assumption of the right of authoritative correlation. Certain excessive practices of this kind have reached a point where protest, if not censure, is merited. There are of course real occasions for new names and even for new systems of names, but every author is likely to overestimate the need of nomenclature in the case he has in hand, and every organization is likely to overestimate the weight of its authority. The practice of imposing new names should be held in reasonable restraint out of regard for the common convenience of the readers of the literature of the science, professional as well as non-professional.

More important than even this, however, is the desirability of keeping the path clear for a final and really satisfactory nomenclature when the appropriate historic, dynamic, classificatory, and other work that must precede a good and lasting nomenclature shall have been adequately done. This can be attained only by wide and careful study, guided by restraint, equipoise, and sagacity; and the results so reached should be approved by adequate trial before they are harnessed to final names. Pending this, the individual worker may well be allowed much liberty in the use of such terms as may suit his purpose, *if*—and this is a vital point—these are regarded as mere temporary and personal conveniences, and are held to be quite without claim to a place in an "adopted" nomenclature except as that claim shall rest upon inherent merit. The "adoption" and formal imposition of names, *as by authority*, is only tolerable when it is preceded by the only sanction of authority which the higher canons of science respect, ***inherent merit based upon adequate investigation.***

The association is eminently wise in the adoption of its resolutions and it is to be hoped that the organizations to which it has addressed them will respond by a hearty co-operation, and that the end will be such wise control of the growth of our nomenclature as shall give it, at length, the highest practicable serviceability.

T. C. C.

The celebration of the hundredth anniversary of the founding of the Geological Society of London, which took place recently, was an event of more than ordinary interest in that it not only signalized the great age of the society, the oldest of all geological societies, but, in calling to mind how near the beginning of geological science it had its birth, as was done by the presidential address of Sir Archibald Geikie, it emphasized the comparatively rapid development of geology as a branch of knowledge. Almost all the advancement from the realm of speculation to that of established facts has taken place during the lifetime of the Geological Society, a very great part of it having occurred within the memory of the oldest geologists present at the meeting, and in fact having been accomplished to a considerable extent by their labors.

While the function of the Centenary meeting was almost wholly social, consisting as it did, of a reception of delegates by the president of the society, Sir Archibald Geikie, an address by him, and a banquet to all the guests in the evening of the first day, followed by another banquet and a general reception on the second, together with numerous smaller entertainments of a social character, there were extended geological excursions before the meeting and shorter ones afterward. Throughout these events there was such evidence of forethought and consideration for the comfort and welfare of the guests as to reflect great credit on those who planned and managed them, and to afford a new example of proverbial English hospitality.

The Centenary meeting was also interesting because of the representative character of the geologists whom it brought together from all parts of the world. For besides the large number of British and Colonial geologists in attendance, there were 94 from foreign countries, of whom 50 were from France, Germany, and America in nearly equal numbers; the other countries represented by smaller number being Sweden, Belgium, Holland, Russia, Austria-Hungary, Norway, Denmark, Switzerland, Egypt, Greece, Italy, Portugal, Mexico, and Japan, in the order given. The opportunity of renewing friendships and of exchanging ideas with colleagues from such widely remote regions was the most important feature of the meeting, and one that makes for a better understanding among geologists and a certain advancement of the science.

After the celebration in London the visitors in two groups were entertained most hospitably by the Universities of Cambridge and Oxford, and the honorary degree of Doctor of Science was conferred upon a number of the most distinguished Europeans: from Germany, Professor Ferdinand Zirkel and Professor Hermann Credner of Leipzig, Professor A. Penck of Berlin, and it was known that Professor Rosenbusch of Heidelberg would have received the degree had he been able to be present; from France, Professor Charles Barrois of Lille, Professor A. Lacroix and Professor A. de Lapparent of Paris; from Norway, Professor W. C. Brögger and Dr. Hans Reusch of Christiania; from Sweden, Professor A. G. Nathorst of Stockholm; from Switzerland, Professor A. Heim of Zurich; and from Belgium, Professor Louis Dollo of Brussels. That no honor was conferred at this time upon any geologist of the English-speaking peoples of America or of the British Colonies is remarkable, considering the quality and amount of work done by the older and ablest geologists in these vast territories. We trust that this inaction on the part of the great English Universities will not be misinterpreted as a lack of appreciation on their part of the attainments of the most distinguished of Colonial and American geologists, but will be attributed to causes not at present understood by those outside the Universities' councils.

J. P. I.

Reviews

Invertebrate Paleontology of the Upper Permian Red Beds of Oklahoma and the Panhandle of Texas. By J. W. BEEDE. (*Kansas University Science Bulletin,* Vol. IV, No. 3, March, 1907, pp. 115–72, Plates V–IX.)

It will be remembered by those familiar with the literature of the Red Beds of the Kansas-Texas region that in 1902 Dr. Beede first described, in this same periodical, a small invertebrate fauna from the Whitehorse sandstone of Oklahoma, concerning which he stated at that time that "there can be but little doubt that the age of these beds is Permian."

It will aid one in understanding the stratigraphy of this region to state that Professor Gould has classified the rocks of Oklahoma, from the base of the Permian upward, as follows:

(1) Enid formation, 1,500 feet thick, which "includes all the rocks of the Red Beds from the base of the Permian to the lowermost of the gypsum ledges;" (2) Blaine, 100 feet thick, containing the lower gypsum beds; (3) Woodward, 425 feet thick, in the upper part of which is the Whitehorse sandstone;. (4) Greer, 275 feet thick, containing the upper gypsum beds; (5) Quartermaster, 300 feet thick, which is capped by the Tertiary.

The systematic portion of the present paper contains a further elaboration of the Whitehorse fauna together with a description of a new one from a sandstone in the Quartermaster formation in the Panhandle of Texas. In Professor Gould's classification the Quartermaster division is given as the highest one of the Red Beds and Dr. Beede says that "the fossils came from well up in this formation." It is also stated that the types of the entire Quartermaster fauna were sent Dr. T. W. Stanton, who reported that they were unmistakably Paleozoic.

Dr. Beede says that "these collections are of great importance, as they furnish the final evidence that the Red Beds, below the Dockum beds, of the Oklahoma-Panhandle region are Paleozoic in age. . . . . The faunas are somewhat heterogeneous as to origin. Some of the species seem to be directly derived from the Kansas Permian or Pennsylvanian, while others, as pointed out in the discussion of the species, are derived from the European Permian, especially that of Russia." The description of these faunas is an important contribution to American geology, since it relatively determines

the age of a considerable thickness of rocks which heretofore on lithologic and stratigraphic evidence had been "referred to anything from the Permian to the Tertiary."

The discussion of the faunas and the descriptive part are preceded by an excellent "Historical Review" in which the geologic literature of this region is very fully discussed. In this review certain facts are brought out which are important to those interested in the age of the upper Paleozoic deposits of Kansas. It is stated that "Gould has shown that the Whitehorse sandstone is identical with Cragin's Red Bluff formation of Kansas," which is well toward the top of the Kansan Red Beds. The Wreford limestone of Kansas, which in his later papers the writer has regarded as the provisional base of the Permian, as followed south into Oklahoma, changes into the Payne sandstone that has been traced by Kirk to the vicinity of Norman in the latter state, and is supposed to mark the base of Gould's Enid formation. "Cope, Cummins, and C. A. White have demonstrated that the Wichita (including the Albany) and Clear Fork beds of Texas are unmistakably Permian. . . . . Williston and Case have demonstrated that the lower Enid formation of Oklahoma is Permian and of similar horizon to some parts of the Wichita and Clear Fork divisions of Texas."

Dr. Beede states that vertebrate specimens from Cowley County in southern Kansas, described by Dr. Williston in 1897, came from the Garrison formation about fifty feet below the Wreford limestone. Dr. Williston in describing these specimens stated that "we have here an interesting series of forms, so closely resembling the species described by Cope from Danville Ill., that I cannot distinguish them specifically. It would seem to demonstrate the contemporaneity of the two formations, and also that of the Texas Permian, whence the species of all these genera have been described by Cope." The presence of these Permian vertebrates, together with a Permian flora in the Garrison formation, favors its reference to the Permian, and perhaps the Cottonwood limestone at its base is really nearer the line of division between the Pennsylvanian and Permian than the Wreford limestone at its top. The top of this former limestone is near the horizon originally suggested by the writer for a tentative line of division between these two systems. The identification of Permian plants by David White and Sellards, Permian insects by Sellards, Permian invertebrates by Beede, and Permian vertebrates by Williston and Case, from the Kansas deposits which have been referred to the Permian by the writer seem to support the correctness of that correlation and to demonstrate that the base of the Permian is certainly as low as the horizon of the Wreford limestone.

CHARLES S. PROSSER

Synopsis of Mineral Characters. By RALPH W. RICHARDS. New York: John Wiley and Sons, 1907. Pp. 99.

This is a compact little book, strongly bound in leather, and of convenient size for the pocket. Minerals, mineralogical terms and tests, are all arranged alphabetically. The descriptions are concise and accurate and include all the more essential properties of the species described. The book will be useful both to students in the laboratory and field, and to miners and others who are interested in minerals.

C. W. W.

Fifty-seventh Annual Report of the New York State Museums for 1903, containing the Twenty-third Report of the State Geologist, 1903. Albany, N. Y., 1905.

Contains articles on peat, the gypsum industry, abrasives, distribution of Hudson Schist and Harrison Diorite in part of the Oyster Bay quadrangle, the northeast extremity of the pre-Cambrian Highlands. In the appendices are "The Geology of the Vicinity of Little Falls, Herkimer Co.," by H. P. Cushing; "New York Mineral Localities," by H. P. Whitlock; "Report of the State Paleontologist, 1903," by J. M. Clarke; "Feeding Habits and Growth of *Venus mercenaria,*" J. L. Kellogg.

Molybdenum. By E. C. ANDREWS. Pamphlet No. 4, Geological Survey, Mineral Resources, Department of Mines and Agriculture, New South Wales. Pp. 17. Sydney, 1906.

The ore of molybdenum is molybdenite in quartz. It is directly associated with intrusions of fine "sandy" granite about which the ore forms contact deposits. One mine produces practically all the molybdenite from New South Wales. Its output in 1904 was 25¼ tons, value £2,726.

Cambrian Faunas of China. By CHARLES D. WALCOTT. (Proceedings of the U. S. National Museum, Vol. XXIX, pp. 1–106. Washington, D. C., 1905.)

Faunas embracing 48 genera and 172 species are listed from three formations in the upper and middle Cambrian. Five new genera and about 125 new species and varieties are described. The upper Cambrian faunas are related to those of North America and northwestern Europe. This is a preliminary report, published in advance of a fuller one with plates, that will appear this year.

C. W. W.

The Petroleum Industry of Southeastern Illinois. By W. S. BLATCHLEY. Bulletin No. 2, Illinois State Geological Survey. Pp. 109, 5 plates. Urbana, Ill., 1906.

The report discusses the history of the petroleum industry in Illinois, the oil-producing rocks and their structure, theories of origin, mode of occurrence, and production of oil in the state. There is also a description of the various oil and gas fields. C. W. W.

The Composition and Character of Illinois Coals. By S. W. PARR. *The Distribution of the Coal Beds of the State.* By A. BEMENT. *Tests of Illinois Coals under Steam Boilers.* By L. P. BRECKENRIDGE. Bulletin No. 3, Illinois State Geological Survey, Pp. 86. Urbana, Ill., 1906.

Geology and Mineral Resources of Mississippi. By A. F. CRIDER. (Bulletin No. 283, U. S. Geological Survey. Pp. 99, 4 plates, including a colored geological map of the state.) Washington, D. C., 1906.

Four Cretaceous, seven Tertiary, and two Quaternary formations are described, generally with especial reference to their economic possibilities. The mineral resources include clays (which furnish nine-tenths of the state's income from mineral sources), ochre, glass-sand, cement rocks, and iron-ore. C. W. W.

Clays: Their Occurrence, Properties and Uses, with Especial Reference to Those of the United States. By HEINRICH RIES. New York: John Wiley & Sons. London: Chapman & Hall, Limited. 1906, pp. 290, 44 plates.

This book is a summary of our present knowledge of clays. It treats of the origin and the chemical and physical properties of clays, the kinds of clays, and the methods of mining and manufacture. The occurrences of clay are described by states, the clays of each geological period being treated separately. C. W. W.

Igneous Rocks of the Eastern Townships of Quebec. By JOHN A. DRESSER. (Bulletin of the Geological Society of America, Vol. XVII, pp. 497–522, Plates 67, 68.) Rochester, N. Y., 1906.

The rocks of southeastern Quebec present two petrographic provinces: I. (*a*) Porphyry-andesite series, extrusive and probably pre-Cambrian;

(*b*) Diabase-serpentine group, early Cambrian to late Silurian; (*c*) Granites, intrusive, late Devonian; (*d*) Later dikes. II. The Alkaline province of the Monteregian hills described by Adams. C. W. W.

Investigations Relating to Clays. By the UNITED STATES GEOLOGICAL SURVEY in 1905. (Extract from Bulletin No. 285, Contributions to Economic Geology, 1905.)

Contains: "Clays of Garland County, Ark.," by Edwin C. Eckel; "Clay Resources of Northeastern Kentucky," by W. C. Phalen; "Clays of Western Kentucky and Tennessee," by A. F. Crider; "Clays of the Penobscot Bay Region, Maine," by E. S. Bastin; "Clays of Cape Cod, Massachusetts," by Myron L. Fuller; "Notes on Clays and Shales in Central Pennsylvania," by George H. Ashley; "Bentonite of the Laramie Basin, Wyoming," by C. E. Siebenthal. C. W. W.

The Eurypterus Shales of the Shawangunk Mountains in Eastern New York. By JOHN M. CLARKE. Bulletin 107, N. Y. State Museum, pp. 295–310, plates 1–8. Albany, N. Y., 1907.

This important little paper gives conclusive paleontologic evidence for transferring the stratigraphic position of the Shawangunk Grit from the base of the Silurian to the Salina. C. A. Hartnagel had already reached the same conclusion from stratigraphic studies. His views are presented in another paper in the same bulletin. C. W. W.

Geology of Diamond Head, Oahu, Mokokea Caldera. By C. H. HITCHCOCK. (Bulletin of the Geological Society of America, pp. 469–96, plates 59–66.) Rochester, N. Y., 1906.

"Diamond Head is a tuff cone thrown up explosively from beneath the level of the sea, and is to be compared with the Monte Nuovo, near Naples. It was ejected through fossiliferous limestones of Tertiary age, probably Pliocene."

Mokokea Caldera is on the southwest slope of Mauna Loa. The order of events in its history is given, including recent eruptions.

C. W. W.

—ROTCH, A. L. Proof of the Existence of the Upper Anti-Trade and the Meteorological Conditions at Lesser Heights in the Northern Tropics. [Blue Hill Meteorological Observatory, Mass.]

—ROWE, PH.D., J. P. Montana Coal and Lignite Deposits. [University of Montana Bulletin No. 37. Geological Series No. 2. Missoula, Mont., 1906.]

—SCALIA, S. Sopra le Argille Postplioceniche della Vena Presso Piedmonte Etneo (Prov. di Catania). [Estratto dal Rend. della R. Accademia delle Scienze Fisiche e Matematiche di Napoli Fascicolo 4°—Aprile, 1906.]

—SCHREINER, O., AND FAILYER, G. H. The Absorption of Phosphates and Potassium by Soils. [U. S. Department of Agriculture, Bureau of Soils Bulletin No. 32. Washington, 1906.]

—SCHWARTZ, A.R.C.S., F.G.S., E. H. L. South African Paleozoic Fossils. [From Records of the Albany Museum. Vol. I, No. VI, issued June, 1906.]

——— Coast-Ledges in the South-West of the Cape Colony. [From the Quarterly Journal of the Geological Society, Vol. LXII, pp. 70–87. February, 1906.]

——— The Rivers of Cape Colony. [From The Geographical Journal for March, 1906.]

——— The Thickness of the Ice-Cap in the Various Glacial Periods. [Extracted from the Geological Magazine, Decade V, Vol. III, No. 501, March, 1906.]

—Science Year Book, The, for 1907. [London, 1907.]

—SHAFER, G. D., Histology and Development of the Divided Eyes of Certain Insects. [Proceedings of the Washington Academy of Sciences, Vol. VIII, pp. 459–86. Pls. XXIV–XXVII. Washington, March 6, 1907.]

—SKIFF, F. J. V. Annual Report of the Director to the Board of Trustees for the Year 1906. [Field Museum of Natural History Publication 119. Report Series, Vol. III, No. 1. Chicago, January, 1907.]

—SLICHTER, C. S. The Underflow in Arkansas Valley in Western Kansas. [U. S. Geological Survey. Water-Supply and Irrigation Paper No. 153. Series K, Pumping Water, 12. Series O, Underground Waters, 50. Washington, 1906.]

—SLICHTER, C. S., AND WOLFF, H. C. The Underflow of the South Platte Valley. [U. S. Geological Survey. Water-Supply and Irrigation Paper No. 184. Series K, Pumping Water, 13. Series O, Underground Waters, 65. Washington, 1906.]

—SLOCUM, A. W. A List of Devonian Fossils Collected in Western New York, with Notes on Their Stratigraphic Distribution. [Field Columbian Museum.

Publication No. 113. Geological Series. Vol. II, No. 8. Chicago, June 1, 1906.]

—SMALL, A. W. The Relation between Sociology and Other Sciences. [Reprinted from the American Journal of Sociology, Vol. XII, No. 1, July, 1906.]

—SMITH, B. Phylogeny of the Races of Volutilithes petrosus. [From the Proceedings of The Academy of Natural Sciences of Philadelphia, March, 1906.]

—SMITH, E. A. The Underground Water Resources of Alabama. [Geological Survey of Alabama. Montgomery, 1907.]

—SMITH, J. P. The Paragenesis of the Minerals in the Glaucophane-Bearing Rocks of California. [Reprinted from Proceedings of the American Philosophical Society, Vol. XLV, 1907.]

—SMITH, W. D. Contributions to the Physiography of the Philippine Islands. 1. Cebu Island. [Reprinted from The Philippine Journal of Science. Published by the Bureau of Science of the Philippine Government, Manila, Vol. I, No. 10, December, 1906.]

—Smithsonian Institution, Annual Report of the Board of Regents of, for the Year ending June 30, 1904. [Report of the U. S. National Museum. Washington, 1906.]

—Société Belge de Géologie de Paléontologie et d'Hydrologie, Bulletin de la. Vingtième Année, Tome XX, Fascicule III–IV. 1906. [Bruxelles, février, 1907.]

—Sonder-Abdruck aus dem Protokoll der Monatsberichte No. 9, Jahrg. 1905 der Deutschen Geologischen Gesellschaft.

—SPRINGER, F., AND SLOCUM, A. W. Hypsocrinus, a New Genus of Crinoids from the Devonian. [Field Columbian Museum. Publication No. 114. Geological Series, Vol. II, No. 9. Chicago, June 1, 1906.]

—State Geological and Natural History Survey of Connecticut, Second Biennial Report of the Commissioners of the, 1905–1906. [State of Connecticut Public Document No. 47. Bulletin No. 9. Hartford, 1906.]

—STEINMANN, G. Die Entstehung der Kupfererslagerstätte von Corocoro und verwandter Vorkomnisse in Bolivia. [Sonder-Abdruck aus der Festschrift zum siebzigsten Geburtstage von Harry Rosenbusch gewidm. v. seinen Schülern. Stuttgart, 1906.]

—STEVENSON, J. J. Carboniferous of the Appalachian Basin. [Bulletin of the Geological Society of America, Vol. XVII, pp. 65–228. Rochester, May, 1906.]

—STEWART, J. B. Effects of Shading on Soil Conditions. [U. S. Department of Agriculture, Bureau of Soils Bulletin No. 39. Washington, February 14, 1907.]

—TARR, R. S. Watkins Glen and Other Gorges of the Finger Lake Region of Central New York. [Reprinted from The Popular Science Monthly, May, 1906.]

—TARR, R. S., AND MARTIN, L. Glaciers and Glaciation of Yakutat Bay,

Alaska. [Reprinted from Bulletin of the American Geographical Society, Vol. XXXVIII, March, 1906.]

—— Recent Change of Level in Alaska. [From The Geographical Journal for July, 1906.]

—— Recent Changes of Level in the Yakutat Bay Region, Alaska. [Bulletin of the Geological Society of America, Vol. XVII, pp. 29–64, Pls. 12–23. Rochester, May, 1906.]

—Van Horn, F. B. The Mineral Production of Illinois in 1905. [State Geological Survey, Urbana, 1906.]

—Wahnschaffe, F. Zur Kritik der Interglavialbildungen in der Umgegend von Berlin. [Sonder-Abdruck aus den Monatsberichten der Deutschen Geologischen Gesellschaft, Jahrg. 1906, No. 5.]

—Walcott, C. D. Algonkian Formations of Northwestern Montana. [Bulletin of the Geological Society of America, Vol. XVII, pp. 1–28, Pls. 1–11. Rochester, May, 1906.]

—— Twenty-Seventh Annual Report of the Director of the United States Geological Survey to the Secretary of the Interior, 1905–6. [U. S. Geological Survey, Washington, 1906.]

—Washington Academy of Sciences, Proceedings of the. [Vol. VII, 1905. Washington, June, 1905—March, 1906.]

—Weller, S. Kinderhook Faunal Studies. IV. The Fauna of the Glen Park Limestone. [Transactions of The Academy of Science of St. Louis. Vol. XVI, No. 7. December 11, 1906.]

—— The Geological Map of Illinois. [Illinois State Geological Survey. Bulletin No. 1. Urbana, 1906.]

—White, C. A. Biographical Memoir of John Strong Newberry. 1822–92. [Read before the National Academy of Sciences, April 17, 1902. Washington, 1907.]

—Whitfield, R. P. Notes on Some Jurassic Fossils from Franz Josef Land, Brought by a Member of the Ziegler Exploring Expedition. [Extracted from Bulletin of the American Museum of Natural History, Vol. XXII, Article VII, pp. 131–34. New York, May 26, 1906.]

—Whitney, M. Soil Fertility. [U. S. Department of Agriculture. Farmer's Bulletin No. 257. Washington, 1906.]

—Wieland, G. R. Dinosaurian Gastroliths. [Reprinted from Science, N. S., Vol. XXIII, No. 595, pp. 819–21, May 25, 1906.]

—— Gastroliths. [Reprinted from Science, N. S., Vol. XXV, No. 628, pp. 66, 67, January 11, 1907.]

—Wilckens, O. Zur Geologie der Südpolarländer. [Separat-Abdruck aus dem Centralblatt für Mineralogie, Geologie und Paläontologie, Jahrg. 1906. No. 6. Stuttgart, 1906.]

—Willis, B. Carte Géologique de L'Amérique du Nord. Geological Map of North America. [Mexico, 1906.]

—— Reports on Geological Investigations. Geological Exploration in

Eastern China—Studies in Europe—Geological Research in Continental Histories—Artesian Water Conditions at Pekin, China. [Extracted from the Fourth Year Book of the Carnegie Institution of Washington, pp. 192–220. Washington, 1906.]

—Wilson, A. W. G. On the Glaciation of Orford and Sutton Mountains, Quebec. [From The American Journal of Science, Vol. XXI, March, 1906.]

——— Physiography of the Archean Areas of Canada.

Woolsey, L. H. Economic Geology of the Beaver Quadrangle, Pennsylvania. [U. S. Geological Survey. Bulletin No. 286. Series A, Economic Geology, 74. Series B, Descriptive Geology, 93. Washington, 1906.]

—Wright, F. E. A Modification of the Lasaulx Method for Observing Interference Figures under the Microscope. [From The American Journal of Science, Vol. XXII, July, 1906.]

——— Schistosity by Crystallization. A Qualitative Proof. [From The American Journal of Science, Vol. XXII, September, 1906.]

——— The Determination of the Feldspars by Means of their Refractive Indices. [From The American Journal of Science, Vol. XXI, May, 1906.]

Index to Volume XV

XM

Volume XV **Number 8**

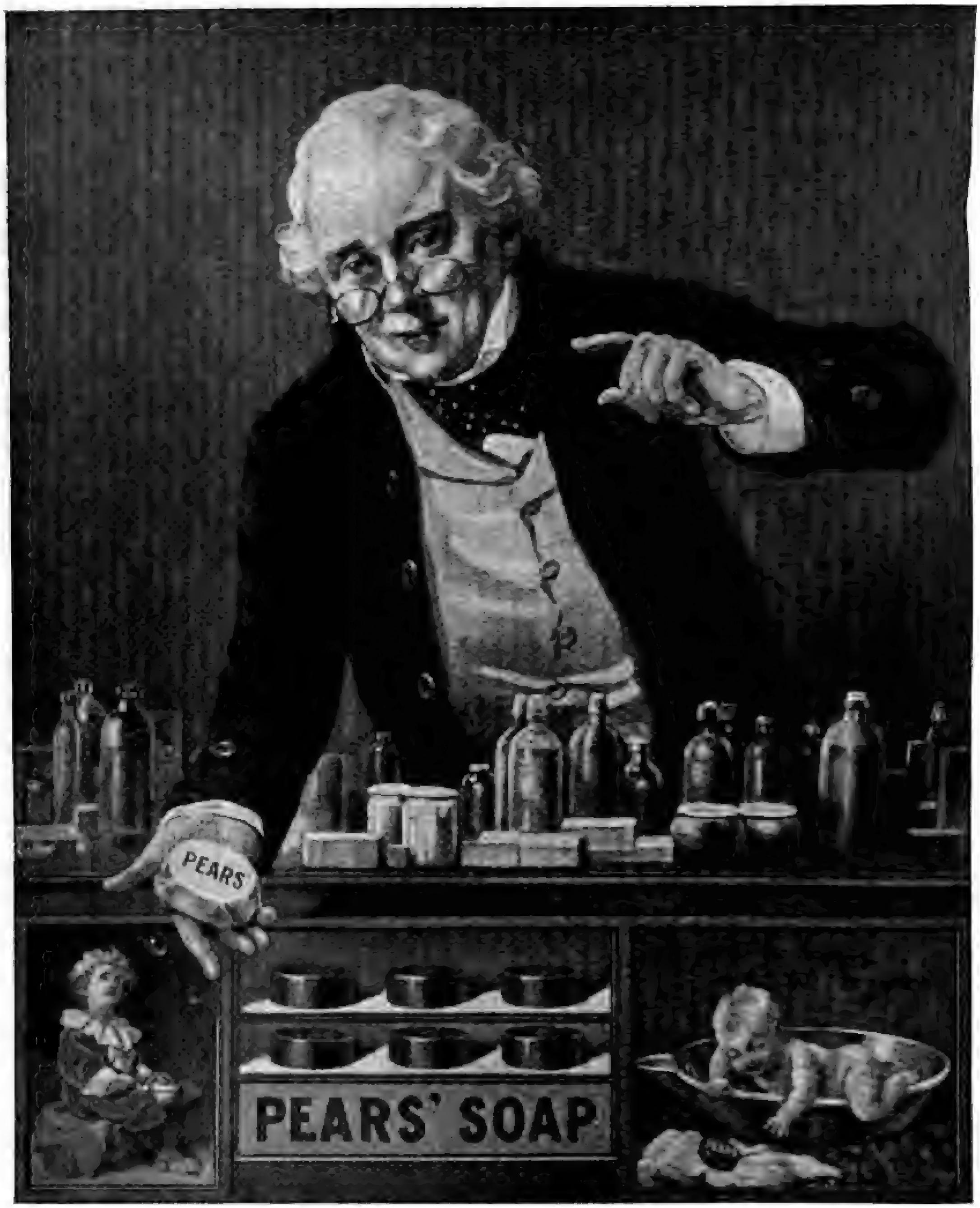
THE

Journal of Geology

A Semi-Quarterly Magazine of Geology and Related Sciences

NOVEMBER-DECEMBER, 1907

The University of Chicago Press
CHICAGO AND NEW YORK
WILLIAM WESLEY & SON, LONDON


PEARS
PEARS' SOAP

The Journal of Geology

Published on or about the following dates: February 1, March 15, May 1, June 15, August 1, September 15, November 1, December 15.

CONTENTS FOR NOVEMBER-DECEMBER, 1907

The Journal of Geology is published semi-quarterly. ¶The subscription price is $3.00 per year; the price of single copies is 50 cents. ¶Postage is prepaid by the publishers on all orders from the United States, Mexico, Cuba, Porto Rico, Panama Canal Zone, Republic of Panama, Hawaiian Islands, Philippine Islands, Guam, Tutuila (Samoa), Shanghai. ¶Postage is charged extra as follows: For Canada, 30 cents on annual subscriptions (total $3.30), on single copies, 4 cents (total 54 cents); for all other countries in the Postal Union, 53 cents on annual subscriptions (total $3.53), on single copies, 11 cents (total 61 cents). ¶Remittances should be made payable to The University of Chicago Press and should be in Chicago or New York exchange, postal or express money order. If local check is used, 10 cents should be added for collection.

William Wesley & Son, 28 Essex Street, Strand, London, are recognized as European agents and are authorized to quote the following prices: Yearly subscriptions, including postage, 14*s.* 6*d.* each; single copies, including postage, 2*s.* 6*d.* each.

Claims for missing numbers should be made within the month following the regular month of publication. The publishers expect to supply missing numbers free only when they have been lost in transit.

Business correspondence should be addressed to The University of Chicago Press, Chicago, Ill.

Communications for the editors should be addressed to them at The University of Chicago, Chicago, Ill.

Contributors are requested to write scientific and proper names with particular care and in citations to follow the form shown in the pages of the Journal.

Separates, if desired, must be ordered in advance of publication. Separates of leading articles will be printed as ordered, of which 50 (without covers) will be furnished *gratis*, the actual cost of the remainder (and covers, if desired) to be paid for by the author. The table below shows the *approximate* cost of separates consisting of plain text or text with line engravings. The actual cost may vary from the figures given, and will depend upon the amount of work in re-making the pages into forms, press work, paper, binding, etc. Separates containing half-tones may be expected to cost somewhat more than the rates given, the increase depending upon the number of cuts and the amount of work required upon them.

Number of copies	50	100	150	200
Letter-press, for 4 pages or less	$1.30	$1.60	$1.80	$2.00
Letter-press, for 8 pages or less	1.80	2.20	2.50	2.80
Letter-press, for 16 pages or less	3.20	4.00	4.65	5.30
Single plates (1 double=2 single)	.80	1.10	1.35	1.60
Covers, with title (paper like Journal cover)	1.20	1.69	2.00	2.40

Entered March 20, 1893, at the Post-Office at Chicago, Ill., as second-class matter, under Act of Congress, March 3, 1879.

Bulletin of Recent Publications and Winter Announcements of The University of Chicago Press

English Poems

Selected and Edited, with Illustrative and Explanatory Notes and Bibliographies, by WALTER C. BRONSON, Professor of English Literature, Brown University

Vol. IV, The Nineteenth Century, 635 pages, 12mo, cloth; net $1.00, postpaid $1.15. Special Library Edition, net $1.50, postpaid $1.68

In preparing this series, Professor Bronson is providing for college students and others a more convenient and generally available selection of English poetry than has ever been made before. When completed it will comprise four volumes. Volume I will include Old-English poems in translation, Middle-English poems, early drama, and old ballads; Volume II will cover the Elizabethan and Caroline periods; Volume III will be devoted to the Restoration and the eighteenth century; while Volume IV (now ready) covers the nineteenth century. The volumes are being issued at intervals of about six months.

The plan of "The Nineteenth Century" is thus described in the preface:

Authors and poems have been chosen both for their merit and for their significance in the history of English literature. The book is therefore not an anthology, or collection of the best poems. It is a collection of good poems that illustrate the different periods and phases of the work of individual poets, and the rise, growth, and decline of schools of poetry. . . . . Entire poems have been given wherever that was possible, and the bulk of the book is made up of them. But in order to represent some authors at all adequately it has been found necessary to admit a limited number of extracts. The notes include (1) explanations of words, allusions, etc., which the average college student may find obscure; (2) statements by the author or his friends which throw light on the meaning of a poem, or give circumstances connected with the composition of it, or illustrate the poet's method of work; (3) the poet's theory of poetry and his philosophy of life, when these can be given in his own words; (4) variant readings of a few poems, such as "The Ancient Mariner" and "The Palace of Art," the reworking of which has special interest and significance; (5) quotations from sources and parallel passages, or references to them, to show the poet's literary relationships and his way of handling raw material; (6) extracts from contemporary criticisms on some of the leaders of new literary movements. A selected bibliography, adapted to the needs of undergraduates, follows the notes.

Heralds of American Literature

By ANNIE RUSSELL MARBLE

394 pages, 11 plates, small 8vo, cloth; net $1.50, postpaid $1.64

Recounts in detailed study and largely from original sources the lives and services of a group of typical writers of the Revolutionary and National periods. There are biographical and critical studies of Francis Hopkinson, Philip Freneau, John Trumbull and his friends among the "Hartford wits," Joseph Dennie, William Dunlap, and early playwrights, and Charles Brockden Brown and his contemporaries in fiction. The book is illustrated by several half-tones of rare portraits, broadsides, and title-pages.

Literature in the Elementary School

By PORTER LANDER MacCLINTOCK

320 pages, 12mo, cloth; net $1.00, postpaid $1.12

The book gives a series of detailed studies on the choice and teaching of the various kinds of stories; on poetry; on the drama; on myth as literature; on the correlation of literature with the other disciplines; on the actual teaching of the class in literature; on the return to be asked from the children; a chapter on out-of-school reading for children; and finally a list of titles in literature for each of the elementary grades, offered as a suggestion to the inventive teacher, but also defended as a working programme tested by experience.

THE UNIVERSITY OF CHICAGO PRES

The True Nature of Value

By RUFUS FARRINGTON SPRAGUE

190 pages, 12mo, cloth; net $1.00, postpaid $1.10

Mr. Sprague is not a professional economist, but a successful manufacturer, whos attention has been for many years directed to the abstract principles underlying exchang In the public discussions of a few years ago on the subject of a monetary standard he took a important part, and he was the candidate of the "Gold Democrats" for governor of Michi gan. He has developed a theory of exchange value which resembles in some points that c Bastiat, but is much more elaborately developed and in many respects entirely new. Th book deserves the attention of all economists.

A Short History of Wales

By OWEN EDWARDS, Author of *The Story of Wales*, etc.

162 pages, 12mo, cloth; net 75 cents, postpaid 83 cents

This book, by one of the most distinguished of living Welsh scholars, will supply a lon felt want. It aims at giving the general reader a simple and intelligible outline of the histor of Wales, and is particularly fitted to be used as supplementary reading in schools. I covers the entire history from prehistoric times to the present day. The volume is full equipped with summaries, pedigrees, and maps.

First Year Mathematics for Secondary Schools

By GEORGE WILLIAM MYERS, Professor of the Teaching of Mathematic and Astronomy in the College of Education of the University of Chicago Assisted by the Instructors in Mathematics in the University High School

198 pages, 12mo, cloth; net $1.00, postpaid $1.09

The object of this new course in mathematics is to do away with the present artificia divisions of the subject and to give it vital connection with the student's whole experience The first year of secondary work is devoted (1) to generalizing and extending arithmetical notions, (2) to following up the notions of mensuration into their geometrical consequences, and (3) to reconnoitering a broadly interesting and useful field of algebra. This means postponing the scientific and purely logical aspects of algebra to a later period.

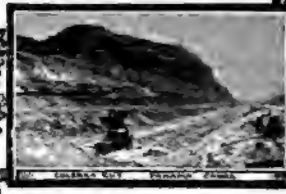
Geometric Exercises for Algebraic Solution, for Secondary Schools

By GEORGE W. MYERS and the Instructors in Mathematics in the University High School

90 pages, 12mo, cloth; net 75 cents, postpaid 82 cents

This book supplies means for holding, through the second year geometry course, the ground made in algebra during the first year. By the use of geometric problems to be algebraically solved the course serves the three-fold purpose (1) of keeping algebraic procedure in continual use, (2) of holding the unity of the geometrical course intact, and (3) of pointing out many connecting by-ways and overlapping districts of the two domains of elementary mathematics.

OUR COLONIAL EMPIRE



What will be the real issue in the next presidential campaign? Some say the tariff; others say the trusts. Both are right, but even more important than these will be our colonial policy. Every American knows that we must face the questions raised by the Philippines and Cuba. They have already involved us in one war. Will they involve us in another?

THE WORLD TO-DAY for 1908 will not neglect the trusts and the tariff, but it believes that the time has come for a broad and intelligent discussion of

OUR COLONIAL EMPIRE

During the coming year we shall publish as a leading feature two groups of articles on this important need. One, comprising seven articles, will be descriptive, and will describe the life, resources and opportunities offered America in the

PHILIPPINES	**CUBA**	**PANAMA**
HAWAII	**PORTO RICO**	**ALASKA**

The amount of information at our disposal, the new photographs we shall reproduce, and the interest in the subjects themselves, will make this series one of the most readable and fascinating ever published in any magazine. The contributors are recognized authorities. Another group of articles will deal with the problems which these possessions raise. They will consist of five discussions by some of the most prominent men in America of the following subjects:

1. ***Can the United States Afford to Have Colonies?***
2. ***Can the United States Defend Its Colonies?***
3. ***Can the United States Administer Its Colonies?***
4. ***Can the United States Americanize Its Colonies?***
5. ***How Could the United States Give Up Its Colonies?***

THE WORLD TO-DAY for December will contain the first article of the first series. **It** will be the first of two elaborate articles on

THE PHILIPPINES

By HAMILTON M. WRIGHT, Author of "A Handbook of the Philippines."

Mr. Wright is one of the best known authorities on the Philippines and the article will be fully illustrated ***in colors*** from new photographs taken by him especially for the purpose.

CARTOONS IN COLOR

Another striking and novel feature of THE WORLD TO-DAY for 1908 will be a series of Cartoons in Color by the well-known artist, G. C. Widney. They are not caricatures, nor personal, nor partisan, but real works of art—"Editorials in Color," on great themes of current interest.

These are but two of the many strong features that give THE WORLD-TO-DAY an individuality of its own. THE WORLD TO-DAY is a world review, but not a lifeless record of events. The reader will find in it illuminating and fascinating discussions of living events and **living** people. No matter how many magazines you take, it is different from them all.

The only Magazine of its Class at a Popular Price of $1.50 a Year.

Send $1.50 for a full year, or at least for a trial subscription of **3 Months for 25 Cents.** Fill in coupon and mail at once. If you read the first article on OUR COLONIAL EMPIRE you will want them all.

THE WORLD TO-DAY CO., Chicago

THE WORLD TO-DAY, 67 Wabash Avenue, Chicago
Enclosed find remittance of $1.50 / 25¢ for which please
send ***The World To-Day*** for 12 / 3 months.
Name
Street
Town
State